Population Vulnerability for Earthquake Loss Estimation using Community Based Approach with GIS

Pratima Singh
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by

Pratima Singh

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Thesis Assessment Board

Chairman: Dr. Ir. R.V. Sliuzas
External Examiner: Dr. Ir. D.J.M. Hilhorst
Internal Examiner: Dr. Cees J. van Westen
First Supervisor: Ir. M.J.G. Brussel
Second Supervisor: Drs. Paul Hofstee

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
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Abstract

Earthquake is one of the most destructive natural hazards that can occur at any time without any warning. It is difficult to predict with the current state of scientific knowledge when a seismic prone region/ocean/city/settlement will experience an earthquake. Cities particularly in developing countries, which usually do not have disaster preparedness plans in place and the population often resides in buildings that are vulnerable to natural hazards. Natural hazards constitute in many cases an acute development problem and the costs of prevention, especially such a simple step as a vulnerability analysis, are a fractional part of development costs and in terms of lives saved and physical damage avoided, the benefits are immense.

In such a backdrop, it becomes extremely vital to study and evaluate the vulnerability of existing buildings and population in cities and determine the expected direct losses in the event of an earthquake. Such seismic risk assessment is a crucial ingredient for forecasting the expected losses; which in turn is a requirement for the preparation and establishment of Disaster Management Plans (DMP).

For undertaking population vulnerability, details of buildings in which people reside/work/study and their presence within these buildings needs to be determined. While details on buildings are obtainable to an extent with the urban local bodies, detailed information of population that is usually available, is based upon Census surveys which only take into account the night time population that is essentially residential and not the actual population presence round the clock. Therefore there is a need to develop methods for mapping population distribution in space and time. Communities form an important stakeholder in disaster mitigation and management, the local knowledge and intrinsic data recording and updating systems often present in the communities, is invaluable and can be an important input to a DMP especially when Geographic Information Technology (GIT) is used.

The present research for a part of Dehradun city (located in seismically active region) looked into the aspects of determining the building and population loss by way of inventory of building stock and studying population activity patterns; and how a community based approach using local knowledge as well as data can re-enforce GIS based population vulnerability assessment. Also, determining how existing CBOs can contribute to the city level DMP.

Broad conclusions of the research are that in a predominantly residential area, population distribution varies considerably diurnally and census sources for exercises such as vulnerability assessments are inadequate. The communities are potential sources as well as sinks of information on their demographic characteristics and such information can be converted into a highly updated form of data which can in turn be used for exercises such as vulnerability assessment. There is a need for expansions of role of existing community based organisations operating in the city and linking them with the efforts of Urban Local Bodies (ULBs) and DMMC; the CBOs active role in preparedness towards natural disasters will lead to speedier development and effective implementation of DMPs.
I take this opportunity to thank a number of individuals and organisations without whom this report would not have been completed.

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I dedicate this work to my Parents and Anant – who is as old as the duration of completion of this report.

Pratima Singh

Enschede, March 2005
Table of contents

1. Introduction.......................................................................................................................................... 1
   1.1. Background...................................................................................................................................... 1
   1.2. Research Issue and Justification..................................................................................................... 2
   1.3. Problem Definition .......................................................................................................................... 3
   1.4. Main Research Objective................................................................................................................ 4
       1.4.1. Research Objectives ............................................................................................................... 4
       1.4.2. Key Research Questions ......................................................................................................... 4
   1.5. Research Methodology .................................................................................................................. 5
   1.6. Usefulness of the Research ............................................................................................................ 5
   1.7. Limitations of the Study .................................................................................................................. 6
   1.8. Structure of the Report ................................................................................................................... 7

   2.1. Introduction....................................................................................................................................... 9
   2.2. Natural Hazards ............................................................................................................................. 9
   2.3. Losses due to Earthquakes ............................................................................................................ 10
       2.3.1. Building Losses .................................................................................................................... 10
       2.3.1.1. Vulnerability Atlas for India ........................................................................................ 10
       2.3.1.2. Factors affecting Building Vulnerability ..................................................................... 11
       2.3.2. Population Losses ................................................................................................................. 12
   2.4. Assessing Activity Patterns for determining Population Distribution ......................................... 13
       2.4.1. Activity Based Approaches and Patterns ............................................................................. 13
   2.5. Community Vulnerability and Community Based Disaster Management ............................... 16
       2.5.1. The Government of India and UNDP’s DRMP (2002-2007) ............................................... 17
   2.6. Use of Remote Sensing Data and Aerial Photographs for Population Estimation ................. 18
   2.7. Classified Traffic Volume Assessment ....................................................................................... 19
   2.8. GIS based approach for Risk Assessment and Loss Estimation ............................................. 19
       2.8.1. GIS for Building Loss Estimation ........................................................................................ 19
       2.8.1.1. HAZUS ........................................................................................................................ 19
       2.8.1.2. RADIUS ....................................................................................................................... 21
       2.8.1.3. Recent Efforts towards Building and Population Loss Estimation .................................. 21
       2.8.2. GIS for Population Loss Estimation ..................................................................................... 22
   2.10. Summary .................................................................................................................................... 23

3. The Case Study City and Area ........................................................................................................... 24
   3.1. Introduction..................................................................................................................................... 24
   3.2. Geographical Location .................................................................................................................. 24
   3.3. Physiography and Topography ..................................................................................................... 24
3.4. Climate .......................................................................................................................... 24
3.5. Connectivity .................................................................................................................. 25
3.6. Geology ........................................................................................................................ 25
3.7. Historical Context of the City .................................................................................... 25
3.8. Population ..................................................................................................................... 25
3.9. Built-up Structures ....................................................................................................... 27
3.10. Building footprint map of Dehradun in GIS ............................................................... 27
3.11. Landuse ....................................................................................................................... 27
  3.11.1. Physical Growth Pattern of the City ..................................................................... 28
3.12. Infrastructure ............................................................................................................ 28
  3.12.1. Water Supply ....................................................................................................... 29
  3.12.2. Power .................................................................................................................. 29
  3.12.3. Transport .............................................................................................................. 30
3.13. Development Planning and Disaster Management Institutions ......................... 30
  3.13.1. Mussorie Dehradun Development Authority ....................................................... 30
  3.13.2. Dehradun Municipal Corporation ........................................................................ 30
3.14. Issues plaguing the city ............................................................................................. 31
3.15. Earthquakes in the past affecting Dehradun and the Doon Valley Region ............... 31
3.16. Summary .................................................................................................................. 32
4. Data Collection and Preparation ..................................................................................... 33
  4.1. Data Collection ........................................................................................................... 34
    4.1.1. Secondary Data Collection .................................................................................. 34
    4.1.2. Primary Data Collection ..................................................................................... 34
    4.1.3. Road Inventory and Surveys .............................................................................. 38
    4.1.4. Building Surveys ................................................................................................. 39
      4.1.4.1. Activity Pattern Surveys ................................................................................ 40
      4.1.5. Sampling ............................................................................................................ 40
    4.1.6. Collection of Other Information ......................................................................... 41
  4.2. Holidays Observed in the City .................................................................................. 41
    4.2.1. Community Based Organisation ........................................................................ 42
      4.2.1.1. Civil Defence .................................................................................................. 42
      4.2.1.2. Community Based Workshop ...................................................................... 45
  4.3. Data Preparation ....................................................................................................... 46
    4.3.1. Change of Projection System of the IKONOS Imagery ...................................... 47
  4.4. Geo referencing of Individual Field survey analogue maps ..................................... 48
    4.4.1. Digitisation ........................................................................................................ 48
      4.4.1.1. Digitisation of Roads ....................................................................................... 49
      4.4.1.2. Digitisation of Buildings ............................................................................... 49
      4.4.1.3. Creation of Junctions ..................................................................................... 49
    4.5. Summary ................................................................................................................ 50
5. Building Vulnerability Assessment .................................................................................. 51
5.1. Introduction ................................................................................................................................. 51
5.2. Buildings in the Study Area ........................................................................................................... 52
  5.2.1. Building Occupancy Classes .................................................................................................. 53
    5.2.1.1. Specific Building Occupancy ...................................................................................... 53
  5.2.2. Building Configuration (Shape) ............................................................................................. 55
5.2.3. Building Materials ..................................................................................................................... 56
    5.2.3.1. Roof ............................................................................................................................. 56
    5.2.3.2. Wall Material ............................................................................................................... 57
    5.2.3.3. Floor ............................................................................................................................ 58
  5.2.4. Building Condition .................................................................................................................. 58
    5.2.4.1. Visible Cracks .............................................................................................................. 58
    5.2.4.2. Condition of Walls ....................................................................................................... 58
5.3. Building Vulnerability Assessment ............................................................................................... 59
  5.3.1. Preparation of Damage Matrices ............................................................................................ 59
5.4. Determining Spatial Location of Buildings with probability of Total Collapse and Partial Damage .......................................................................................................................... 62
  5.4.1. Recoding and Standardisation of Parameters for Analysis ...................................................... 62
5.5. Community Based Risk and Resource Mapping ........................................................................ 64
5.6. Comparison of Results (GIS based as well as Community based) ............................................. 65
5.7. Summary ...................................................................................................................................... 66
  6.1. Introduction ................................................................................................................................. 67
  6.2. Population Presence ................................................................................................................... 68
    6.2.1. Population Presence in Buildings ..................................................................................... 68
      6.2.1.1. Population Presence in Buildings ............................................................................. 69
      6.2.1.2. Population Presence in House ................................................................................... 70
      6.2.1.3. Population Presence in House in Time Slabs ........................................................... 71
      6.2.1.4. Population Presence in House ................................................................................... 72
      6.2.1.5. Floating Population .................................................................................................... 73
    6.3. Population Distribution ............................................................................................................. 73
  6.4. Variations in Population Activity Patterns .................................................................................. 76
    6.4.1.1. Profile of Population Groups .......................................................................................... 78
    6.4.2. Population Presence on Road Network ............................................................................. 80
    6.4.3. Computation of Persons on Roads based upon Traffic Volume Counts ............................ 81
  6.5. Summary ...................................................................................................................................... 85
7. Population Vulnerability Assessment and Upscaling at city level .................................................. 87
  7.1. Introduction ................................................................................................................................. 87
  7.2. Population Vulnerability Assessment .......................................................................................... 87
    7.2.1. Number of Severity of Casualties in case of a Scenario Earthquake .................................... 87
    7.2.2. Number of People present in these buildings .................................................................... 88
  7.3. Up scaling Population Vulnerability Exercise at City Level ....................................................... 89
7.3.1. Building Database Generation for the entire city ................................................................. 89
7.3.2. Potential Sources of Information from Community ............................................................... 89
7.3.3. Need for expansion of CBOs role towards preparedness from impacts of Hazards ............ 90
7.3.4. Exploring other sources of data/information on population presence ................................. 91
7.4. Summary ................................................................................................................................... 91

8. Conclusions and Recommendations .................................................................................................. 93
8.1. Conclusions .................................................................................................................................. 93
8.1.1. Building Vulnerability Analysis ........................................................................................... 93
8.1.2. Population Distribution and Vulnerability ........................................................................... 93
8.1.2.1. Population Distribution within buildings .................................................................... 93
8.1.2.2. Population Distribution outdoors ................................................................................ 94
8.2. Recommendations ..................................................................................................................... 94
8.2.1. Need for expansion of CBOs role towards preparedness from impacts of Hazards .......... 94
8.2.2. Exploring other sources of data/information on population presence ................................. 95
8.2.3. Conduction of detailed population distribution exercise for population outdoor environment ........................................................................................................................................................................... 95

References ............................................................................................................................................. 96
Appendix II Road Survey (Traffic Volume and Characteristics) Form ................................................ 101
Appendix III Building Survey Questionnaire .................................................................................. 102
Appendix IV Household/Enterprise Profile and Activity Survey ..................................................... 103
Appendix V: Database format of Building Survey Information ....................................................... 103
Appendix V: Database format of Building Survey Information ....................................................... 104
Appendix VII Building Vulnerability Analysis ................................................................................... 104
Appendix VII Recoding of Sub Types of Building Condition Parameters ........................................ 107
Appendix VIII: Population Vulnerability Analysis ............................................................................. 109
Appendix IX: Number of Students in Schools within Sector A and Schedule of Religious Place .... 111
Appendix X: Average % & number of people present in residence(HH), shop, other units & schools during the day ............................................................................................................................................... 113
Appendix XI Road Population Distribution Analysis ......................................................................... 115
Appendix XII Attributes of Road Section in Geometric Network .................................................... 117
List of figures

Figure 1-1 Research Methodology............................................................................................................... 6
Figure 2-1 Framework of Analysis of Activity Patterns .............................................................................. 14
Figure 2-2: General Model for Explaining Activity Patterns .................................................................. 15
Figure 3-1: Location of Dehradun in India .............................................................................................. 24
Figure 3-2 Population Growth in Dehradun............................................................................................... 26
Figure 3-3 Ward wise Population Density............................................................................................... 26
Figure 3-4 User wise % of Electricity Connections in Dehradun Municipal Limits .................................. 29
Figure 4-1 Framework for Analysis ....................................................................................................... 33
Figure 4-2 Ward boundaries (with case study ward encircled) over laid on the IKONOS, copyright Space Imaging, 2001 .................................................................................................................................. 35
Figure 4-3 Division of Ward into Blocks (overlaid on IKONOS, copyright Space Imaging, 2001) ........ 37
Figure 4-4 Traffic Survey (left) and Junctions Surveyed (right) ............................................................... 38
Figure 4-5 Modes of travel and Road Scenario in Sector A ..................................................................... 39
Figure 4-6 Samples Selected for Activity Pattern Survey ....................................................................... 40
Figure 4-7 Household Activity Pattern Survey ........................................................................................ 41
Figure 4-8 Various types of days that can have influence on activities of people.................................... 42
Figure 4-9 Sector wise maps of Khudbura: Prepared for present study analysis (left map) and that prepared (right map) by CBO (Civil Defence) ....................................................................................... 43
Figure 4-10 Numbers of People Age Sex wise in Sector A ..................................................................... 44
Figure 4-11 Entity Relationship Diagram ............................................................................................... 46
Figure 4-12 Geo referencing Model ....................................................................................................... 48
Figure 4-13 Digitisation of Roads and Buildings (features overlaid on IKONOS, ................................ 48
Figure 4-14 Digitised Buildings of Sector A ............................................................................................ 49
Figure 5-1 Building Occupancy in the Khudbura Ward (sector A earmarked by red rectangle) and all (5) sector boundaries shown in inset two dimensional figure ......................................................... 51
Figure 5-2 Separation Distance between buildings ................................................................................ 52
Figure 5-3 Elevated Surface Reservoir in the case study ward ............................................................... 53
Figure 5-4 Dairy (with selling outlet) ....................................................................................................... 53
Figure 5-5 Specific Building Occupancy ............................................................................................... 54
Figure 5-8 Buildings Wall Materials wise in Sector A ........................................................................... 57
Figure 5-9: Cracks, Delaminating and Dampening of Wall .................................................................... 59
Figure 5-10 Geophysical Survey sites location in Dehradun .................................................................. 60
Figure 5-11 Vulnerable Buildings (based upon building) ...................................................................... 63
Figure 5-12 Risky Buildings in Sector A as identified by the community .............................................. 64
Figure 6-1: Average % of household members in house at every hour different days .......................... 70
Figure 6-2 Presence of people in various occupancy classes ................................................................. 76
Figure 6-3 Population Distribution at various hours in different building occupancies of Sector A ...... 77
Figure 6-4 Jagran in the case study ward (Sector B); dilapidated ....................................................... 78
Figure 6-5: Average presence of Housewives in house on a weekday ........................................ 79
Figure 6-6: Average presence of school going children in house on a weekday ....................... 80
Figure 6-7: Junctions surveyed (left) with traffic data (right) ..................................................... 81
Figure 6-8: Total persons present outside buildings (on road segments) and inside buildings .... 83
Figure 6-10: Average Speed of Vehicles on roads ................................................................. 84
Figure 7-1: Injury Severity Description .................................................................................... 88
Figure 7-2: Number of People present in buildings and injury severity estimates .................. 88
List of tables

Table 3-1 Details of City Built up area and Floor wise Structures ................................................................. 27
Table 3-2: Details available in the Building Footprint Map .............................................................................. 27
Table 3-3: Existing Land use Pattern in Dehradun, 1982 ............................................................................... 28
Table 3-4 Details of users and consumption of electricity .............................................................................. 29
Table 3-5: Earthquakes in Uttranchal Himalaya Region .................................................................................. 32
Table 4-1 Household Details Maintained in the Civil Defense Register ...................................................... 44
Table 4-2 Age Sex Distribution ...................................................................................................................... 44
Table 4-3 List of Risks and Resources for Community Based Mapping .......................................................... 45
Table 4-4 Projection System Details .............................................................................................................. 47
Table 5-1 Building Occupancies in Case Study Ward .................................................................................... 52
Table 5-2 Specific Building Occupancy in Sector A ....................................................................................... 54
Table 5-3 Age distribution (# & %) of ............................................................................................................. 55
Table 5-4 Building Shapes in Sector A ........................................................................................................... 55
Table 5-5 Roof Types in Sector A .................................................................................................................. 56
Table 5-6 Building Wall Material in Sector A ............................................................................................... 57
Table 5-7 Floor Material of Buildings in Sector A ......................................................................................... 58
Table 5-8 Building Condition of surveyed buildings .................................................................................... 58
Table 5-9 Probability of damage to various types of buildings in Sector A ..................................................... 60
Table 5-10 Damage probability for each building wall material type .......................................................... 61
Table 5-11 Number of Buildings in each Vulnerability Class ....................................................................... 63
Table 6-1 Details of Sampled Households/Enterprise .................................................................................. 69
Table 6-2: Average % of People Present in a residence on different days of the year .................................. 70
Table 6-3: Population presence in house time slab wise .............................................................................. 71
Table 6-4 Presence of people in various occupancy classes ......................................................................... 75
Table 6-5 : Vehicle Occupancy Rates ........................................................................................................ 81
## List of Abbreviations and Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBDM</td>
<td>Community Based Disaster Management</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GIT</td>
<td>Geographic Information Technology</td>
</tr>
<tr>
<td>GoI</td>
<td>Government of India</td>
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<tr>
<td>HH</td>
<td>Household</td>
</tr>
<tr>
<td>HAZUS</td>
<td>Hazards U.S.</td>
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<tr>
<td>IIRS</td>
<td>Indian Institute of Remote Sensing</td>
</tr>
<tr>
<td>MS</td>
<td>Mild Steel</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>NSET</td>
<td>National Society for Earthquake Technology</td>
</tr>
<tr>
<td>RB</td>
<td>Reinforced Brick</td>
</tr>
<tr>
<td>RCC</td>
<td>Reinforced Cement Concrete</td>
</tr>
<tr>
<td>PCC</td>
<td>Plain Cement Concrete</td>
</tr>
<tr>
<td>NIDM</td>
<td>National Institute for Disaster Management</td>
</tr>
<tr>
<td>DMC</td>
<td>Dehradun Municipal Corporation</td>
</tr>
<tr>
<td>DMMC</td>
<td>Disaster Mitigation and Management Council</td>
</tr>
<tr>
<td>DMP</td>
<td>Disaster Management Plans</td>
</tr>
<tr>
<td>DMU</td>
<td>Disaster Management Unit</td>
</tr>
<tr>
<td>DRMP</td>
<td>Disaster Risk Mitigation Programme</td>
</tr>
<tr>
<td>GSDMA</td>
<td>Gujarat State Disaster Management Agency</td>
</tr>
<tr>
<td>MDDA</td>
<td>Mussorrie Dehradun Development Authority</td>
</tr>
<tr>
<td>SLARIM</td>
<td>Strengthening Local Authorities in Risk Management</td>
</tr>
<tr>
<td>ULB</td>
<td>Urban Local Bodies</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
</tr>
<tr>
<td>ITC</td>
<td>International Institute For Geo-Information Science And Earth Observation</td>
</tr>
<tr>
<td>IDRN</td>
<td>India Disaster Resource Network</td>
</tr>
<tr>
<td>IIRS</td>
<td>Indian Institute of Remote Sensing</td>
</tr>
<tr>
<td>UA</td>
<td>Urban Agglomeration</td>
</tr>
<tr>
<td>MC</td>
<td>Municipal Corporation</td>
</tr>
<tr>
<td>RBC</td>
<td>Reinforced Brick Concrete</td>
</tr>
<tr>
<td>SDI</td>
<td>Spatial Data Infrastructure</td>
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<td>DBM</td>
<td>Base Data Management</td>
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1. Introduction

1.1. Background

Earthquake is one of the most destructive natural hazards of geological origin. Moreover, earthquakes may occur at any time without any warning and can destroy buildings, infrastructure and above all lead to human loss or injury. It is difficult to predict with the current state of scientific knowledge when an earthquake will occur although we know the probable regions and expected magnitude based upon seismic zonation maps. Cities, the engines of economic growth and where population resides in higher concentrations are also vulnerable to hazards such as earthquakes. This is particularly true for cities in developing countries. The vulnerability of cities is due to a number of factors such as rapid growth and inadequate planning, inappropriate construction practices and high population densities, dependency on infrastructure and services, concentration of political, industrial, financial or other resources, etc. (GoI-UNDP, 2004). Besides, local authorities do not have the required technical capacity as well as resources to effectively plan and manage disasters. In such a situation, the role of communities and their organization for disaster preparedness becomes increasingly important.

The Bhuj earthquake of January 26, 2001 in India resulted in the reported loss of about 13,805 people (GSDMA, 2002); approximately more than 30,000 lives were lost in the Bam earthquake in 2003 (Guragain, 2004). The recent Tsunami triggered by an earthquake of 9.0 magnitude on the Richter scale in the Indian Ocean has unfortunately highlighted how vulnerable communities across multi nations can be to natural hazards. It is difficult to predict which region/ocean/settlement/city will be next in line to experience an earthquake.

In such a backdrop, it becomes extremely vital to study and evaluate the vulnerability of existing population and buildings in cities and determine the expected losses in the event of an earthquake striking a particular region/city. Such seismic risk assessment of property as well as population is a crucial ingredient for forecasting the expected losses; which in turn is a requirement for the preparation of Disaster Management Plans (DMPs). DMPs with a clear disaster management strategy are required to mitigate disasters. Although a typical disaster management strategy comprises of the entire cycle that includes disaster prevention, disaster preparedness, disaster relief, rehabilitation and reconstruction; in view of the increasing stress being laid on ‘disaster prevention and preparedness’ by development agencies and governments; this study following similar suite focuses specifically on the vulnerability assessment which forms an important aspect of disaster prevention and preparedness.

Any Seismic Loss Estimation study or project usually includes input information such as building characteristics and population details. While details on buildings are obtainable to a certain extent, detailed information of population is usually available based upon Census surveys that take into account the population residing in the area and this is essentially the night time population. Thus, in
order to determine the expected population being affected by an earthquake, the distribution or presence of people round the clock needs to be established.

1.2. Research Issue and Justification

Most research focus on earthquake phenomenon rather than its possible impact (ITC, 2003). The impact of natural disasters such as earthquakes - which account for one of the highest losses amongst all types of disasters in terms of the number of people affected, the properties and infrastructure affected as well as the cost to the local, regional and global economy; is significant as well as alarming – this has been amply depicted in the aftermath of the Tsunami of December 26, 2004.

By the year 2000, half of the urban dwellers in the world’s 50 largest cities will live within 200 km of faults that are known to produce earthquakes of Richter magnitude 7 or greater (Tucker et.al., 1994). Furthermore, 90% of that population at risk will be in developing countries (Uttio, 1998). Hence population vulnerability needs to be studied carefully and loss estimation needs to be undertaken particularly in the urban areas of developing countries which usually do not have disaster preparedness plans in place and where high concentration of population resides often in buildings that are vulnerable to natural hazards such as earthquakes. The HAZUS methodology is also based on the assumption that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. Such loss estimation would in turn help in the preparation and establishment of disaster preparedness action plans. In every earthquake, vulnerability is heavily concentrated in the areas where the buildings are of poor quality (Guragain, 2004). Rapid urbanization and erratic building construction activity in such countries is one of the major root causes of such building vulnerability.

Vulnerability of buildings directly affects the population, and population loss estimation requires the input of building loss estimation. However, for arriving at higher levels of accuracy on population vulnerability, input of detailed population data representing the distribution and possible variability of people spatially as well as temporally becomes an important requirement. Thus, there is a requirement to know how population vulnerability fluctuates during the day. Appropriate population loss estimation (which could feed into exercises such as emergency planning) that establishes a more realistic scenario, calls for establishing the distribution of people across an urban area. This is particularly required since population information in censuses is usually designed with the idea of characterizing households. Also, typically census data only allows for the mapping of population concentrations during the night since the number of persons sleeping and cooking together in a housing unit is recorded. This entails the requirement of developing methods for mapping population distribution – particularly diurnal distribution. The importance of conducting such a study holds further validity as emphasized by DMU (2003) that undertaking disaster risk management studies should not be significantly delayed until high-grade information is available and that it is important to recognise that mapping of uncertainties may also be useful.

Communities – the affected as a consequence of an earthquake form an important stakeholders in disaster mitigation and management and to have a permanent and effective DMP their involvement is essential. The local knowledge and intrinsic data recording and updating systems often present in the
communities, is invaluable and can be an important input to such a plan especially when Geographic Information Technology (GIT) is used.

Since natural disasters such as earthquakes are spatial in their manifestation, the role of Geographic Information Technology (GIT) becomes highly useful. The present study deals with population and buildings loss estimation with the help of GIT such as Geographic Information System (GIS).

It is worth mentioning that the area of work is also a part of the ongoing Strengthening Local Authorities in Risk Management (SLARIM) project at ITC. The topic is also of interest for the curriculum (including research) for the joint M Sc course offered by ITC and Indian Institute of Remote Sensing (IIRS) and two M Sc students conducted research on Seismic Response Analysis Generation of Geological Database for Seismic Microzonation and Generation of Geological Database for Seismic Microzonation of Dehradun city in the northern part of India.

1.3. Problem Definition

The city of Dehradun in India is located in seismically active region (seismic zone IV). As per the 2001 Census of India, the city has a population of about 0.5 million. Dehradun is the interim capital of the newly (as of 2000) formed state of Uttrakhand in North India. Due to this recent upgradation of the city’s role, higher rates of urbanization is being witnessed and the city is expanding rapidly. Although, newly formed building control regulations have been introduced, many of the older parts of the city have very high population densities (as much as around 300 persons per hectare). The buildings and lifelines in the city have low earthquake resistance (GoI-UNDP, 2003).

The threat of a potential natural disaster such as an earthquake looms large over the city. As the city is not free from any major earthquake hazard, an assessment of the elements at risk (buildings and population) is required in order to determine population vulnerability and loss estimation. This entails the need for study of detailed population activity patterns (in order to establish population distribution especially diurnally) as well as collection of detailed individual building characteristic information.

Efforts for reduction of vulnerability of elements at risk are needed on a priority basis. One such effort is that of the Government of India and United Nations Development Programme’s Disaster Risk Management Programme (DRMP) from 2002 to 2007. Under the DRMP is the Urban Earthquake Vulnerability Programme (UEVRP) that deals specifically with urban areas (38 cities in India). Dehradun is one of the selected cities under the UEVRP. The thrust of the DRMP and UEVRP is that it is ‘community based’. The UEVRP programme is underway in Dehradun and since it is community based, the present study includes an overview of the same.

There are two approaches towards efforts to reduce vulnerability – one is the technocratic approach (also can be termed as the ‘Top-Down’ approach) wherein the Government/research institutions/multilateral agency/NGOs undertakes risk assessment without the involvement / participation of the communities.

An example of such a technocratic approach is the application of GIS based loss estimation method such as HAZUS. The second approach is the community-based approach (also can be termed as the
‘Bottom-Up’ approach). The present study hypothesizes that neither of these approaches is complete and may in fact, complement each other in order to determine building and population loss estimation that will ultimately feed into a DMP. By way of such a loss estimation exercise, a framework for the local authority for taking mitigative action to reduce potential damage and losses can be more clearly outlined for embedding into the DMP.

1.4. Main Research Objective

The main research objective was to undertake GIS based population and building loss estimation in conjunction with community-based approach for disaster management.

1.4.1. Research Objectives

The specific objectives along with sub objectives of the research were:

1. To estimate the building and population loss for a part (ward) of Dehradun city.
   - To construct a partial database with elements at risk (population and individual building) related features and attributes from satellite imagery and the field survey data and map.
   - To identify factors determining population vulnerability.
     - To identify the most important population characteristics that play a role in determining their activities.
     - To determine data collection method for population activity pattern spatially and temporally.
   - To identify appropriate GIS operations that allow the integration of these data sets to obtain the desired output.
   - To develop a method for the estimation of population distribution spatially and temporally.
   - To do the damage estimation for buildings under a scenario earthquake.
   - To estimate the number of casualties in case of a scenario earthquake.

2. To study the community-based approach – particularly the risk and resource mapping for disaster preparedness being carried out by GoI and UNDP under the Urban Earthquake Vulnerability Reduction Programme in Dehradun.
   - To undertake risk and resource mapping using community knowledge (based upon UNDP’s methodology).

3. To compare the two results of building loss and risk estimation mentioned in objective 1 and 2.

4. To indicate how results from the research can be used in vulnerability reduction programmes at the city level.

1.4.2. Key Research Questions

The research questions pertaining to each of the objectives have been enlisted hereafter.

Pertaining to Research Objective 1, 2 and 3

What is the basis of assessment for mapping buildings including population distribution and their activities.

Pertaining to Research Objective 2

What method can be used to estimate building and population loss for a given part of Dehradun city.

Which are the important population characteristics that play a role in their activities.

Which are relevant datasets and which are relevant data collection methods for determining population activity patterns.

Which are the appropriate GIS operations that allow the integration of these data sets to obtain the desired output.

Pertaining to Research Objective 3
What is the community-based approach for disaster preparedness being implemented by GoI and UNDP in Dehradun city.

Pertaining to Research Objective 4

How does a GIS based risk assessment approach vary from that of a community-based vulnerability mapping (assessment) approach. How the community based approach contribute to the DMP and how can it be used in vulnerability assessment programmes.

Pertaining to Research Objective 5

How can the results from the research be used in vulnerability reduction programmes.

1.5. Research Methodology

The research methodology has been given in the figure 1-1. The first component (A) deals with the generation of database for the population and buildings as well as roads in the study area and estimating the building and population loss for a part of ward (one sectoriii) of Dehradun city. In component A, the survey research approach was adopted to study population the existing buildings in the ward, to determine the building vulnerability and the activity patterns. The second component (B) dealt with how the community based approach can be useful in identifying risky buildings whereas, the third component (C) looks into how component B can be integrated with the GIS based loss estimation undertaken in the first component (A).

1.6. Usefulness of the Research

The research will be useful in some of the following ways:

- The building database generated for individual buildings will be of multipurpose use such as for municipal planning and management (e.g. cadastral, population registration, etc.).
- The database also serves as an important tool in determining loss estimation which can be a useful input during the disaster preparedness phase for disaster management at the municipal level and embedding the findings of this work in the city level DMP.
- Setting up a system for building permits registration and control, which is one of the most important Earthquake vulnerability reduction measures.
- The database can be a tool for the urban local bodies (ULBs) to determine the effect of certain mitigation measures, for which a cost-benefit analysis can be carried out. The urban local bodies can in-turn could pass on necessary information to individual houses/enterprises/businesses to take mitigation actions to reduce potential damage and losses that might be experienced in the eventuality of an earthquake hitting the city.
- The population distribution methodology would be useful in a variety of applications including emergency planning (for both pre and post disaster), infrastructure planning (transport, water supply, etc.), business planning, etc.
- The findings of the study can be useful in urban planning as well as disaster management, for example, with the help of the methodology appropriate location of evacuation sites in the city can be identified.
Figure 1-1 Research Methodology

1.7. Limitations of the Study

Some of the major limitations of the study have been highlighted hereafter. The direct and indirect economic losses associated with human and capital - the building inventory and; subsequent income losses have not been covered in the present study. Also, the study does not include exposure assessment for the community, schools, etc. in detail in the study area.
As in many GIS based projects, a majority of the time is spent in preparation of database in digital format. Non-availability of data in digital GIS based format resulted in considerable time of the study being spent in preparation of digital database.

As with most analysis – whether GIS based or not; communication, input, and feedback from the beneficiaries and end users (who may be the Urban Local Body, CBOs and the community itself as well as for specific programmes such as UVERP under DMP) are essential. The scope of this study did not deal with this aspect of receiving feedback from the beneficiaries and end users.

1.8. Structure of the Report

The report has been divided into eight chapters as enlisted here below:

*Chapter 1: Introduction*
This chapter provides the background to the study, the research objectives and the research methodology. This is followed by the mention of the usefulness and limitations of the study.

*Chapter 2: Population Loss Estimation and Community Based Approach for Earthquake Preparedness: a Literature Review*
This chapter discusses about natural hazards such as earthquakes, activity based approaches and patterns, building loss estimation, traffic volume assessment, GIS based risk and loss estimation and community based approach.

*Chapter 3: The Case Study City and Area*
This chapter provides a snap shot view of the case study city – Dehradun in terms of its location, land use, housing, infrastructure, development planning institutions and a brief description of earthquakes affecting the city and its surrounding region.

*Chapter 4: Data Collection and Preparation*
This chapter discusses about the actual data collection process during the field work, details of the community based organisation working in the area and also the post field work process.

*Chapter 5: Building Vulnerability Assessment*
This chapter provides an over view of the building occupancy classes in the entire case study ward and thereafter zooms into the actual building exercise for one part (a sector) of the ward.

*Chapter 6: Population Distribution*
This chapter details out the population distribution both within buildings as well as outside buildings.

*Chapter 7: Results and Discussion and Possible Institutional Linkages*
This chapter looks into determining population vulnerability as a consequence of building damage/collapse and thereafter embarks on presenting an outline of how such an exercise of determining population vulnerability (including building vulnerability) can be scaled up to the city level.

*Chapter 8: Conclusions and Recommendations*
This chapter states the conclusions and recommendations of the present study.
2. Population Loss Estimation and Community Based Approach for Earthquake Preparedness: a Literature Review

2.1. Introduction

This chapter reviews literature on Population Loss Estimation and Community Based Approach for Earthquake Preparedness. Besides; the topic of activity pattern approaches, traffic volume assessment, building loss estimation, GIS based approach for risk assessment and loss estimation have also been included as these are related to the subject of population loss estimation and community based approach.

2.2. Natural Hazards

Natural hazards and disasters are defined as major disruptions of livelihoods and economic processes as a result of extreme weather-related or geological hazards combined with vulnerable human systems. Disasters can be caused by telluric hazards, such as earthquakes or volcanic eruptions, or by meteorological events (severe storms, tidal surges, windstorms, hail, snowstorms, hurricanes and drought) and their hydrological and geomorphological responses - floods, mudflows, landslides and coastal erosion. Much of disaster related research has centered on the study of hazards, geared essentially to a better understanding of these recurrent natural cycles (IUCN, et.al).

What really defines a disaster is the combination of physical, biological or technological hazards with such factors as economic wealth, population growth and migration as well as the resulting configuration of human settlement. Together these create patterns of vulnerability (IUCN, et.al).

Risk for urban areas is increasing rapidly, especially in developing countries (which usually do not have adequate organization, prevention and evacuation systems and/or disaster preparedness plans in place or either, the same are not in effect), whereas; the developed countries have devised various ways of protecting themselves from the consequences of disasters by anticipating their risks through prevention and planning measures. Few such measures have been taken in the developing countries, however, where a large proportion of the population lives in precarious conditions. (ECLAC, 1991). Also, the impact on economic development is usually considerable, although capital stock losses may be less.

Earthquake occurrences in seismically prone areas cause colossal damage to housing and infrastructure and prove to be a major setback factor for urban areas – especially those that are located in highly seismic prone zones. The vulnerability of buildings and infrastructure systems depends on
the type of risk involved, in combination with the physical (structural) characteristics of the buildings and infrastructure involved and factors associated with the environment.

Some of the major conclusions of a paper published by the Office of the United Nations Disaster Relief Coordinator way back in 1978 were that natural disasters constitute in many cases an acute development problem and that the costs of prevention, especially such a simple step as a vulnerability analysis, are a fractional part of development costs and that, in terms of lives saved and physical damage avoided, the benefits are incalculable.

2.3. Losses due to Earthquakes

Earthquakes cause high mortality resulting from trauma, asphyxia, dust inhalation (acute respiratory distress), or exposure to the environment (i.e. hypothermia). Also, they lead to injuries, burns and electroshocks. Some other impacts are those related to damage to buildings, essential facilities (especially health facilities) and lifeline facilities such as water and sewerage systems, energy lines, roads, telecom and airports. Earthquakes have impacts that can be direct or indirect in nature. These impacts can in turn lead to direct and indirect losses. The HAZUS methodology, developed by the Federal Emergency Management Agency (FEMA) under contract with the National Institute of Building Sciences (NIBS) of the United States is a nationally applicable standardized methodology and software program that contains models for estimating potential losses (classified losses into direct and indirect from hazards such as earthquakes).

The direct nature of losses includes mainly those physical in nature viz. (building stock, essential and high potential loss facilities, life-line transportation and utility systems which lead to inundation, fire hazmat, debris); and; the indirect economic/social losses include casualties, shelter, effects in the economy (e.g. - taking the example of the tourism sector). Thus, direct economic losses are comprised of manmade assets destroyed in the earthquake plus the reductions in economic activity i.e. Gross Output – sales volume, Value- Added, or Gross National Product- (GNP). The indirect economic losses are an offshoot of the direct economic loss. It is worth noting that in order to get a complete picture of the economic impact of the disaster, both the direct and indirect economic losses or gains should be considered.

Population data is fundamental to the estimation of levels of societal risk (Mooney et.al). In public risk assessments, the common measure of consequence is typically the impact on humans exposed to each type of hazard (www.questconsult.com).

2.3.1. Building Losses

2.3.1.1. Vulnerability Atlas for India

Approach to address the building losses due to earthquakes and the associated parameters have been discussed hereafter.

Vulnerability Atlas for India has been prepared as a follow up of the “Yokohoma Strategy for a Safer World” adopted in World Conference on Natural Disaster Reduction by the Expert Group constituted

A combination of local hazard intensity and vulnerability of existing house types based on observed performance; has been the input data for the risk analysis exercise.

The damage risk assessment has not, however, been taken up systematically except that some building damage scenarios for earthquakes in Himachal Pradesh, Uttar Pradesh and Bihar has been prepared.

Also, the vulnerability Atlas provides state wise hazard maps and district wise damage risk tables for the country i.e. at the macro level or use by the authorities concerned with natural disaster mitigation, preparedness and preventive actions and hence; there is a need for such atlases at the micro level particularly in the urban areas which have high concentrations of population, non-retrofitted (and un-engineered) houses and sometimes even essential facilities.

2.3.1.2. Factors affecting Building Vulnerability

The factors that affect the building vulnerability can be subdivided in primary and secondary factors (UNDP, 1994 in Guragain, 2004). Primary factors are the sub-soil conditions and building construction materials and; secondary factors are those associated with the inherent deficiencies of a particular building type (such as shape, size, height, age, construction quality, etc.). Elaborating on the effect of such secondary factors - buildings with the same material type however having different variables such as shape in plan as well as elevation, size, height, age, construction quality, etc. would show different behaviour at the same site.

Building shape
Building shape affects the extent of damage that a building would suffer; as in the case of buildings that have a large length to width ration, large height to width ratio, a large offset in plan and in elevation - such buildings behave poorly and suffer greater damage than the regular ones.

Building height
Building height and the natural period of buildings affects the buildings behaviour during occurrence of an earthquake. Apart from the ground vibrating in multi- directions; buildings also vibrate in different directions and hence have multiple modes. Each of these modes has a period and the longest period is known as the natural frequency. If the ground motion frequency is close if or equal to building and the natural frequency is close to or equal to that of the buildings; resonance occurs which amplify the building response. The approximate frequencies of different storied buildings is10 for a one storied building, 2 for a 3-4 storied building, 0.5 to 1.0 for a tall building and 0.17 for a high-rise building.

Building separation distance
Building separation distance plays a major role in the behaviour of every building in case of occurrence of an earthquake as every building has its own natural frequency and with the occurrence of an earthquake, a building can swing according to this frequency. In case two buildings are at a distance, they may be able to sway freely and not hamper the free swaying movement of each other.
However, in case the buildings are close enough to obstruct each others free sway movement; then an effect known as pounding occurs as per FEMA 310. The probable displacement of a building can be found out from a structural analysis and as a thumb rule provided by FEMA 310, the minimum separation distance between two buildings must be 4% of the height of the buildings - this is basically with the assumption that most structures will not drift more than 2% during the occurrence of an earthquake.

The characteristics of building stock and distribution of population were studied by Montoya (2002) for developing a GIS based methodology for urban disaster management. Building and Population risk was addressed by integrating a hazard intensity map, damage curves derived from historical damage records and a building inventory. It was proposed in the study to develop population density scenarios in order to account for mobility throughout the day and during the weekends and make the same available to emergency planners. Day time population density model was designed on the basis of census data and land use map.

**Building Vulnerability Assessment**

Seismic vulnerability of a building is the amount of expected damage induced to it by a particular level of earthquake intensity. It describes the probability of failure of buildings under different levels of ground shaking and is expressed as a per cent loss caused by a particular seismic hazard to the type of building under consideration (UNDP, 1994 in Guragain, 2004). Vulnerability analysis of buildings is helpful for identifying the strong as well and weak points inherent in the construction practice and the materials used in the construction.

Building vulnerability analysis can be done by qualitative and quantitative methods. Qualitative analysis refers to the assessment of vulnerability based upon statistical evaluation of past earthquake damage and is suitable a region having same type of buildings. Also, this method is suitable for non-engineered buildings since it is not possible to get detailed data needed for quantitative analysis.

Quantitative assessment is suitable for engineered buildings which have detailed drawings and design data available and when there is no past earthquake observed building damage data. The assessment is based upon the numerical analysis of the structure; buildings with the same material and construction type are grouped into one class; and; based upon the design specifications and construction detail of the building considered, the performance of the building during an earthquake of an expected intensity is predicted based upon calculations.

**2.3.2. Population Losses**

Conventional population available dataset at the lowest level is at the city ward level. This data is produced and published by the Directorate of Census Operations, Government of India. However, this data set is highly insufficient as it takes into account people cooking together and sleeping under a roof during night. Thus, such data does not provide a true representation of population presence across time and space – an essential component of any risk mapping exercise and loss estimation study – as in the case of the present study.
In terms of the process of collection of data during Census operations, there are two phases – one is the ‘house’ listing operation which when compiled draws up information on housing conditions, availability of the basic amenities such as electricity, drinking water, toilet and bath rooms, ownership of houses and possession of vehicles. In the second phase, canvassing (usually school teachers and other government employees are particularly involved in this phase) of details such as general and socio-cultural characteristics (these include religion, mother tongue, languages known, literacy and educational status), characteristics of workers and non-workers, migration characteristics and fertility particulars. Demographic characteristics basically pertain to people living in an area on a house to house basis. The above mentioned data collected in the Census is published by the Census Commissioner of India as Census Series and Tables. The State Directorates publish State-wise data.

In the 2001 Census, the enumeration of additional demographic characteristics has been done (for the first time) such as age of marriage, disabilities, languages known, distance traveled to place of work and mode of travel, migration after birth, level of education and type of institution attended. Some of these characteristics would be highly useful – for example details of disabled people will not only help in policy decisions in relation to the reservation of jobs available but also for vulnerability assessment exercises.

Past researches have focused on population loss estimation using either census data or data collected for specific time periods. Islam (2004) has utilized population data for four time periods based upon secondary data available from National Society for Earthquake Technology (NSET), Nepal; for population loss estimation. However, neither of the approaches is sufficient for conduction of a detailed loss estimation exercise and hence, detailed population distribution and establishment of population distribution both in spatial as well as temporal terms is required. This calls for determining population distribution in terms of the activity patterns of the population.

2.4. Assessing Activity Patterns for determining Population Distribution

Since the present research has a major objective of determining population densities within a certain area and thus determining activity patterns; hence in this section is included the subject of activity based approaches and about activity based models and patterns.

2.4.1. Activity Based Approaches and Patterns

Majority of the concepts of activity-based approaches in travel behaviours were developed in geography and urban planning. Activity based approaches essentially deal with the issues such as why people travel and how decisions regarding trips are concerned. It looks into peoples travel behaviour and the obligatory and discretionary activities that are dependent upon individuals psychological, economic and social needs. Thus, such approaches are most frequently used for specific needs such as in transportation planning; for gauging the effects that public investments in transportation and infrastructure have on resident living patterns. Major important aspects covered under activity based approaches is that there is a trade-off between the time and cost required for the activities and their priorities and these determine which activities are performed. The other important aspect is that activity performance depends upon availability of specific activities, the household characteristics and
that travel should be regarded in the context of activity patterns consisting of multiple activities and trips.

The first half of the 1970’s saw two approaches being developed - the first by Hagerstrand (1970) and the second by Chapin (1974). Hagerstrand’s approach was about understanding which activity patterns can be realized in particular spatial-functional setting. The sequence of the activities deals with a path through space as well as time that is followed by an individual. There are three constraints to this i.e. capability constraints, coupling constraints and authority constraints.

Chapin (1974), on the other hand, argued that activities result from individual’s basic desires, which drive the propensity to engage in a particular activity (these are discretionary in nature) – refer figure 2.1. For this there are both motivational of energizing (i.e. fulfilment of basic needs, affection, achievement of status and self fulfilment) as well as constraining factors or in other words preconditioning factors (i.e. personal socio-demographic characteristics; the role that society assigns to an individual and appropriateness of timing and circumstances in activity performance; influence of activities by environmental contexts as these provide the facilities and opportunities). Both the preconditioning factors as well as predisposing factors are the independent variables whereas the propensity to engage in discretionary activities is the dependent variable.

![Figure 2-1 Framework of Analysis of Activity Patterns](source: Chapin (1974))
In the descriptive type of investigation, attention is directed towards identifying similarities and differences in activity patterns exhibited by a population under study and among sub societal segments in this population. In the explanatory type of investigation, the concern is with factors postulated as having an influence in shaping these activity patterns. (Chapin, 1974). 

Descriptive phase is the one that deals with assumptions that go with the explanatory phase. The assumptions are: activity patterns of the metropolitan community vary with the cultural makeup (ethnic concentrations which show identity and cohesion) of the community and that they also vary with the social structural context (defined in terms of status concepts that apply within the large community and within the various ethnic groups) of the community and its sub cultural spheres of influence.

The explanatory phase is then concerned with determining the diversity of activity within these subsegments of the community and exploring the influence that role and personal characteristics (pre conditioning factors) and motivations and attitudes (predisposing factors) have in explaining activity patterns.

The Activity Patterns are the dependent variables and activity is a classificatory term for a variety of acts grouped together under a more generic category according to some established activity classification. According to Chapin (1974), the nature and the extent of grouping (and thus the nature and extent of the activity classification system) are dictated by the uses to which activity data are put. Further, Chapin also stated two essential approaches to identifying activity patterns in the field – the first is based on the survey research methods and the other on ethnographic study methods. The survey research approach is workable at national, metropolitan - area and neighbourhood-level studies. In this method activity data is obtained through structured interviews from a probability sample of persons from some pre established universe of subjects by ways such as a check list approach, a field listing of “yesterdays” activities or by the diary approach to “tomorrows” activities.

Activity patterns based upon participation in activities are affected by individuals characteristics and household characteristics. The present study has attempted to delve in basic characteristics of
individual and household characteristics and their activities based upon a sample survey in the case study area discussed in the ensuing chapters.

In terms of activity based models such as CARLA (Jones et al, 1983), BSP (Huigen, 1986), etc. these have been developed in the transportation field and have not been further discussed.

**2.5. Community Vulnerability and Community Based Disaster Management**

Descriptions of community vulnerability also require sufficient detail for risks to be clearly defined. Description of the features of important community elements may assist the understanding of vulnerabilities and, in due course, treatments. The development of good risk (and consequence) information is central to the task of developing useful treatment options based on cost/benefit and other factors. For example, expressions of the vulnerability of people need to provide details such as location, numbers, health issues, economic position, mobility and age. Knowledge of these issues may be of critical importance when evacuation is being considered as a treatment option. Expressions of the vulnerability of engineering lifelines and critical facilities should not only consider damage to infrastructure but should also describe loss of services. For example, the loss of a road may be particularly important if it provides the only means of access to key facilities (e.g. the airport). Similarly, the loss of a small hospital may be relatively unimportant if the services it offers can be provided in another building (DMU, 2003).

Disaster Management comprises of the entire cycle that is involved right from the pre-disaster to the post disaster stage i.e. Mitigation, Preparedness, Disaster event, Relief, Rehabilitation and Reconstruction. Risk assessment and Management are an important components of the Preparedness.

Community based disaster management (CBDM) is described by the International Institute for Disaster Risk Management (IDRM International) as “an approach that involves direct participation of the people most likely to be exposed to hazards, in planning, decision making, and operational activities at all levels of disaster management responsibility” (Jegillos, 2003). The government has to realise that the best decisions are the ones made together with the community and not assume to know the best solution to their problems as very often it is the case (Carazzai, 2002).

The community based approach to disaster preparedness and management is vital especially in the context of developing countries (such as India which has a relatively stronger community participation perspective and practice) where local bodies do not have sufficient technical know-how as well as resources to take up the mapping exercises and entire burden of losses due to disasters. In such a situation, communities form an even more important stakeholder for disaster preparedness.

The CBOs are in general, a very strong institution inside the community and they were created with the intent of fighting for a solution to the problems involving the community (Pugh, 2000).


2.5.1. The Government of India and UNDP’s DRMP (2002-2007)

The crux of the Government of India (GoI) – United Nations Development Programme (UNDP) Urban Earthquake Vulnerability Reduction Programme (UEVRP) is that it is community based. The goal of the Disaster Risk Management Programme (DRMP) is the ‘Sustainable Reduction in Disaster Risk’ in the most hazard prone districts in states of India. The objectives of the programme include National Capacity Building, Environment Building (awareness and capacity building), Multi-hazard preparedness, mitigation and prevention plans and Knowledge networking.

The programme is divided into two phases. The first phase (2002-2004) focuses on Capacity building of Ministry of Home Affairs (MHA) for administrative, institutional, financial and legal mechanism; Multi-hazard plans; Capacity building of Government functionaries, Civil Society and Communities in 28 districts of three states (Bihar, Gujarat and Orissa). A total of US$ 2 million was stipulated to be available from the UNDP Core Resources for programme implementation.

The second phase of the programme focuses on similar objectives as that in Phase one for 169 districts and 17 states besides; it also includes Risk and Vulnerability Indexing and Reporting, Urban Earthquake Vulnerability Reduction in 38 Cities; India Disaster Resource Network (IDRN); Corporate Partnerships; Gender Studies; Climate Change Studies; etc.

The DRMP envisages the following broad components:

- Awareness Generation
- Deployment of preparedness and response plans at the community levels.
- Development of a Technology Regime for the states.
- Capacity building at all levels.
- Knowledge Networking on International and National best practices among all the cities and urban centres in the programme.

The main objectives of the Urban Earthquake Vulnerability Reduction Programme are:

- Creation of awareness among government functionaries, technical institutions, NGOs and communities about earthquake vulnerability mitigation measures.
- Institutionalising Earthquake Preparedness and Response Plans and practice these through mock drills. As part of this objective, the risk and resource mapping (with the involvement of Civil Society, NGOs, Municipal Officials and Community) has been underway in cities such as Bhavnagar, Guwahati, etc.
- Development of regulatory framework (techno-legal regimes) to promote safe construction and systems to ensure compliance.
- Capacity buildings for certification by Government functionaries and professionals (engineers and architects).
- Networking knowledge on best practices and tools for effective earthquake risk management including creation of information systems consisting inventory of resources for emergency operations.
2.6. Use of Remote Sensing Data and Aerial Photographs for Population Estimation

Often spatial population data at the local level (i.e. neighbourhood level) is required for development planning and certainly for establishing population distribution/densities across space and time. To obtain such information about the composition and distribution of population, the census surveys are the most accurate source, however, such information is not always available. Usually, in a country such as India, Census enumerations are carried on a decadal basis and the results are available after much time has elapsed. The figures that are published are at the ward level and not detailed enough for carrying out exercises such as Population Loss Estimations.

This and many other reasons enlisted by van der Zee (1983), resulted in the need for development of appropriate techniques and methods for surveying population rapidly and inexpensively. Remote Sensing Imagery and especially aerial photography can be an important tool in such a method, especially where the spatial aspects should be emphasised. Such approaches have been developed and tested, mostly for urban environments (van de Zee, 1983).

The brief summary of the evaluation of existing literature done by van der Zee (1983) highlights how air photo interpretation can be used to delineate the land use / landscape variations and the land use be subdivided into structure type of categories which are later further subdivided into roof densities. Then subsequently the mean population density is established. Two studies have been briefly described hereafter based upon their extract.

Witensteins (1954-1955-1956) described that by means of air-photo interpretation one can delineate the function patterns i.e. major land use categories. The function categories are then subdivided into structure type of categories which are later further subdivided into roof densities. The areas are delineated based upon their homogeneity in functional, structure type and roof density terms. From each of the characteristic habitation, sample surveys are selected after which a house to house canvas (enquiry) is organised to collect relevant information that can be expanded to the non sampled areas.

Collins and El Beik (1971) applied photo-interpretation techniques in order to obtain information about landuse and population in rapidly changing areas. Also they started with delineating areas of homogeneous housing types. However, the categories distinguished and interpretation criteria used were applicable only to British towns and cities. In sample areas of each type they counted or measured the number of houses to the corresponding population data from a recently held census resulting in an average photographic factor (APF) for each type. This APF was applied to ten more samples per structure type and compared with the corresponding census data to establish the validity of the APF.

It is to be noted that inaccuracies may stem from two main sources viz.-errors connected with identification and counting of dwelling units on the aerial photographs and; errors related to the universal application of an APF to specific areas. (van der Zee, 1983).
2.7. **Classified Traffic Volume Assessment**

Classified Traffic volume studies (for which counts have to be taken) are generally done for Transport Demand Modelling for a base year and the same is used for forecasting the travel demand for horizon years.

Usually for a traffic and transportation study, input data (based upon Road Network Inventory Surveys, Speed and Delay Survey, Classified Traffic Volume Count Survey, Origin-Destination Survey, pedestrian surveys, parking survey, household travel survey, public transport survey) is used for problem identification through computation of parameters such as Volume Capacity (V/C) Ratio, Level of Service (LOS), Degree of Congestion (DOC), Congestion Index (CI), Parking Parameters, Saturation Capacity of Intersections, Pedestrian Movement ($PV^2$ Value).

The four-stage transportation planning process consisting of trip generation, trip distribution, modal split and trip assignment is usually used in practice in India for analysing base year transport data and also for developing and calibrating transport sub-models. Trip Generation comprises of determining the number of person trips (for e.g. most are home based trips in a predominantly residential zone) leaving a zone irrespective of destination and number of trips attracted to a zone irrespective of origin. Trip Distribution deals with linking of trip origins (production) with their destinations (attraction). Modal split is the separation of trips by modes (for example, public transport and private) and trip assignment is the allocation of trips between a pair of zones to the most likely routes on the network.

2.8. **GIS based approach for Risk Assessment and Loss Estimation**

Geographical Information Systems (GIS) are computer software packages that enable the storage, retrieval, manipulation and display of electronic data with a spatial component (Mooney et.al). As disasters such as earthquakes are spatially structured events and may lead to problematic effects, the use of spatially structured information systems such as GIS coupled/not coupled with Remote Sensing can be made in order to support disaster planning, response, mitigation and recovery. In a GIS system, spatial analysis of multivariate data can be done and thus this is a highly useful tool for effective preparedness, communication, and training in the area of disaster management. GIS is a powerful tool for disaster risk managers as it provides a view of risks derived through a comparison of hazard maps and vulnerability maps (DMU, 2003).

2.8.1. **GIS for Building Loss Estimation**

2.8.1.1. HAZUS

HAZUS stands for "Hazards US" which is a standard, nationally (i.e. in United States) applicable methodology for assessing earthquake risk. HAZUS has been designed to produce loss estimates for use by governments (federal, state, regional and local) for earthquake risk mitigation, emergency preparedness, response and recovery. The methodology has a national database embedded within such as demographic aspects of the population in a study region, square footage for different occupancies of buildings, etc. With the methodology and software, loss estimates for a region (in US) can be
carried out. The methodology admits that uncertainties are inherent in any loss estimation methodology – due to incomplete scientific knowledge concerning earthquakes and their effects upon buildings and facilities; due to approximations and simplifications that are necessary for comprehensive analyses, and also as a result of incomplete or inaccurate inventories of the built environment, demographic and economic parameters.

In the few instances where HAZUS have been partially tested using actual inventories of structures plus correct soil maps, it has performed reasonably well (FEMA, 1999).

**Building loss estimation**
In terms of the buildings loss estimation aspect the methodology computes the damage state probabilities of the general building stock at centroid of the census tract. The information required for the analysis to evaluate the probability of damage to occupancy classes is the relationship between the specific occupancy and the model building types\(^{ix}\); this is possible to be computed from the specific occupancy class square footage inventory for each group\(^{x}\) of states.

The building inventory (and also for essential facilities\(^{xi}\) such as) classification comprises of a two dimensional matrix relating building structure (model building with building sub classes) types grouped in terms of basic structural systems and occupancy classes.

Default mapping schemes for specific occupancy classes (except RES1 (i.e. single family dwelling) to model building types by floor area % has been provided based upon information provided by ATC-13 (1985) – in case of buildings for Western Us and; based on proprietary insurance data, opinions of a limited number of experts and inferences drawn from tax assessors records.

FEMA recommends that accurate mapping may be developed on a particular building type distribution within the study region since, the default mapping schemes should be considered as a guide.

**Demographic Data used in HAZUS methodology**
The census data processes for all the census tracts\(^{xii}\) of the US and 29 fields for each census tract are related to total population; total household; age group wise, ethnicity and income of people; total population in residential property during day and night, total working population in commercial and industrial industry, total commuting at 5 pm, total number of units (owner occupied, renter occupied and vacant) and the age of the structure.

The default square footage\(^{xiii}\) estimates for occupancy classes number of people for that occupancy class (FEMA, 1999).

**Direct Physical Damage – General Building Stock**
The methodology for estimation of earthquake damage to buildings (in terms of determining the probability of slight, moderate, extensive and complete damage), based upon data on model building types and an estimate of the level of ground shaking.

Generalised “ranges” of damage are used by the (HAZUS) methodology in order to describe the structural and non structural damage as it is not practical to describe building damage as a continuous
function. Structural and non structural damage states are predicted i.e. ranges of damage or “damage states”.

Capacity and fragility curves are used to estimate the probability of the mentioned damage stages to general building stock.

### 2.8.1.2. RADIUS

The RADIUS method\textsuperscript{xiv} is quite appropriate to prepare fast earthquake scenarios that better fits the need of earthquake-threatened cities in developing countries and for scenario modelling, probable earthquake in the region is taken with magnitude, epicentre, depth and occurrence time. The peak ground acceleration and MMI is taken calculated with empirical formulas. Critical input data are scenario earthquakes, ground\textsuperscript{xv} conditions demographic data and vulnerability functions. The entire study area is divided into zones of 1 to 5 km using Excel based software and for each of the meshes the amount of houses, essential facilities and life lines and probable population are mapped; the input and output in the grid cells are able be visualised spatially as simple raster maps.

As far as building classification\textsuperscript{xvi} is concerned, these are classified into 10 different classes as per the material type, construction type, applied code, uses and number of stories. The building types and the fragility curve described in the methodology are also common building types found in most developing countries. The RADIUS method seems more appropriate for the study of preliminary earthquake hazard and vulnerability assessment (Guragain, 2004).

### 2.8.1.3. Recent Efforts towards Building and Population Loss Estimation

Loss estimation for buildings and population has been done in recent ITC (MSc) studies using remote sensing and GIS tools and techniques based upon homogenous units (i.e. buildings of similar characteristics are grouped together). The important data requirements for such estimation are that on building characteristics (material, number of floors, occupancy class) and population. Guragain (2004) highlighted the lack of building database for vulnerability assessment in the study of Lalitpur in the Kathmandu Valley in Nepal. In the same study, although vulnerability analysis was done based upon samples from different occupancies and representative areas covering the whole area (this was an attempt to create a building database considering the seismic defects in building types\textsuperscript{xvii}; there was no spatial positioning, mapping and interpolation from data sets to cover the study area. Guragain (2004) argues that though it is more practical to group buildings that have the same characteristics together and apply standard vulnerability functions; however; such nature of building information does not provide accurate information. Thus, building information taken individually would lead to more accurate information in terms of spatial location as well as the building characteristics.

The population vulnerability study is based on the result of building vulnerability and on similar lines, Islam(2004) emphasized that analysis considering further sub-division of the homogenous units would lead to a more detailed distribution of population as well as pin point location of casualties.
2.8.2. GIS for Population Loss Estimation

This section is drawn from Mooney et al (2002) who state that previous studies have largely treated human populations as being homogenous "receivers" of hazard events; and that; writers in geographical hazard theory now emphasise the importance of social and economic context. The studies that have been reviewed by Mooney et al (2002) are a range of studies for a diversity of end uses, some of these have been mentioned hereafter.

Martin et al (2000) worked on creating a population surface from census data. He states that using census data in the form that it is available from the ONS (the smallest spatial unit being enumeration districts) has a number of fundamental problems for applications where the local distribution of population over space is important. However, producing a population surface can to an extent address these problems. The paper compares the original method with variations introducing new data and assumptions. The authors state that:

“One of the key obstacles to the evaluation of such models is the absence of definitive high resolution population data against which to compare the modelled distributions.”

Also, Dasymetric mapping, that uses remote sensing (satellite) images to redistribute area-based population figures suffers because:

“On some occasions land covers other than residential (for example, industrial) have been included in the “built” category.”

One solution is that of utilization of unit postcode centroids to add information on population distribution. However, sometimes the poor quality of the available postcode limits the effectiveness of this approach.

Harris and Longley (2000) compare measures of urban density produced using remote sensing and postcode data. The paper argues the benefits of using the two data types together with an example of the possibilities of such a combination as provided by the identification of tower blocks.

LANDSCAN (in Dobson et al (2000) is a global database that attempts to describe the distribution of population in detail. The impetus for deriving this data is the need to respond to “global threats to local places” such as the Bhopal & Chernobyl accidents or major natural disasters. Such events require detailed population data to plan responses, but can occur anywhere on the planet. LANDSCAN has been created by redistributing census counts (obtained at the most detailed level available for each country) across the census collection areas by use of weighting factors. These are generated from global map data layers including:
Roads (the data attempts to portray non-residential population distribution)
Slope (on the basis that most settlement is on flat land)
Land cover class
Populated places (point and areas marking urban land)
Coastlines
A remotely sensed data layer showing the distribution of night time lights is also utilised. Echoing Martin et al, the authors comment that:

“Verification of any spatially explicit global population database is inherently limited by the difficulty of establishing a suitable reference database”

However, some testing of LANDSCAN has taken place by redistributing US, German and Israeli census data. In these cases the redistribution algorithms have been used with census data provided at a level that is not the most detailed available. The detailed data have then been used to test the results.

2.9. Building and Population Loss Estimation Projects: SLARIM

The Strengthening Local Authorities in Risk Management (SLARIM) project has been taken up on the premise that to reduce risk effectively, local authorities require reliable, up-to-date, and interpreted information on the nature and characteristics of present hazards, risks and vulnerabilities.

If risk assessment and management are done properly, it will lead to the elimination, reduction, transfer and acceptance of risk, and in turn to a community that is prepared to deal with the impact of a hazardous event. Thus, it can therefore be seen as the most important aspect of Disaster Management. The objective of SLARIM therefore is the development of a methodology for the implementation of risk assessment and spatial decision support systems for risk management by local authorities (ITC, 2003).

The SLARIM project focuses on the authorities in flood and earthquake threatened urban areas in developing countries since these hazards cause most damage in urban areas. The project comprises of seven work packages i.e. Project management, User needs assessment, Spatial Data Infrastructure(SDI) and Base Data Management(DBM), Flood hazard assessment, Seismic hazard assessment, Elements at risk mapping and Vulnerability and risk assessment. The present study, is a part of the last two packages of the SLARIM project.

2.10. Summary

The review of the literature, encompassing the broad topic of population loss estimation and community based approach for earthquake preparedness provided an over view of many different topics that are directly or indirectly related to population vulnerability. It is clear that there does not seem to be a clear method for establishing building vulnerability at individual building level and also a tested method for population distribution across an area not only spatially but also temporally and also in temporal terms and which, can be aggregated to determine population distribution for units (such as wards in a city) and subsequently for the entire city particularly in developing countries. This further strengthens the need for determining a method that can be applicable to unpredictable natural disasters such as earthquakes.
3. The Case Study City and Area

3.1. Introduction

The present chapter provides an overview of Dehradun – the case study city. The city is the gateway to Gharwal sub-region and Queen of Hills – Mussorie of Uttranchal state and also a market place for surrounding hilly regions. Besides, it is an educational center with some of the best and well known schools in the country located in the city. Apart from schools, many national and international level institutions are located in the city. The city is a service city, an administrative city and is the interim capital of Uttranchal state since the year 2000.

3.2. Geographical Location

Dehradun city is situated at 39° 19' North Latitude and 78° 20' East Longitudes in the southern part of Uttranchal state. The city lies centrally in the Doon Valley just below the Mussorie hills on the foothills of Himalayan Ranges. The city is bounded in the west by River Saung, in the west by river Tons, on the north by Himalayan ranges and the Sal forests in the south.

3.3. Physiography and Topography

Although the city appears to be in plains it has been characterised as being located in a hilly region based upon the Planning Commission’s delineation norms of 1981. The general slope in the city is from the north and south and the southwest. The city is located at 640 m above mean sea level. The lowest part (600 m) is on the southern side of the city, whereas the highest altitude is 1000 m on the northern side of the city. The entire area is heavily dissected by a number of seasonal streams and nallahs locally also known as Khalas.

3.4. Climate

The city has a salubrious climate and the pristine natural beauty form the surroundings of the city. This is one of the major reasons for the city being one of the favourite residential cities especially for retired bureaucrats. The climate of the city is temperate with maximum and minimum temperatures ranging from 5o and 36o respectively. Average annual rainfall in the city is about 2184 mm. It rains
during the monsoon season (from July to almost September end). Temperatures during the winter (mid November to February) range from 7° to 14° degrees; whereas; during the summer the temperatures are in the range from 20° to 30° degrees.

3.5. Connectivity

The city is the last rail head of Northern Railway in the state of Uttranchal. The city is also well connected by road. The nearest airport is Jolly Grant which is 24 km from the city. Dehradun is 255 km from the capital of the country – New Delhi. Also, the city attracts the maximum number of tourists in the state. As per the report of RITES (2004), a total of 0.92 million of domestic and foreign tourists arrived in Dehradun which are more than 7% of the total tourists coming to the entire statexxii. The entire state of Uttranchal is a tourist destination with hill stations and religious places spread over the state. A lot of tourists use the city as a base to travel to these other places of tourist interest. Also, as the city meets the trade and commerce requirements of the city residents as well as the surrounding predominantly hilly region; it seems (based upon field observations and discussions with the city residents) that there is a significant proportion of floating population in the city, the exact figures of which are not recorded.

3.6. Geology

Doon gravels comprising of gravels, sand and soil forms the lithology of the city. The soil type of the city is abundantly sandy loam, with some areas having sandy type of soil. It is pertinent to note that non-engineered buildings on sandy soil are more susceptible to collapse or damage during an earthquake.

The city lies in Seismic Zone IV (based upon the Seismic Zone Map of India) where MMI lies in Richter Scale range of 4 to 9. This was also an important factor for taking up the present study in Dehradun (apart from other factors such as Dehradun being one of the 38 cities where the UEVRP is being implemented by GoI and UNDP).

3.7. Historical Context of the City

In the 17th century the Sikh Guru, Guru Ram Rai built a temple (Gurudwara) at the village of Dharamwala around which the city was established. Khurbura (also the case study ward for the present study) formed the nucleus of the city. The then King of Garhwal – Fateh Shah endowed the Gurudwara with three villages – Khurbura, Rajpur and Chaman Sari. Pratap Shah the successor of Fateh Shah added four other settlements. The 18th century witnessed construction of new roads and improvement works were commissioned by the British who colonized India then. The growth of the city was further accelerated with the establishment of two Military Cantonments in 1872 and 1902. During this period, the ‘Centre for Technical Training in Forestry for South East Asia Region’ (now known as Forest Research Institute) was also set up.

3.8. Population

The city urban agglomerationxxiii has a population of nearly 0.53 million as per the 2001 Census (refer figure 3-1). The corresponding population of the municipal area is nearly 0.33 million. The city is the largest city in the state of Uttranchal state.
As can be seen from the figure 3-1, between the years 1971 and 1981, the city recorded a decadal growth of about 44% and between 1981 and 2001 the decadal growth was 27% and 66%. The high growth rate between 1991 and 2001 can be due to the declaration of the city as the interim capital of the newly created state of Uttrakhand.

Households
In 1991, there were 53438 households in the city, the % of Scheduled Castes and Tribes (often viewed as a more vulnerable group) was nearly 12% and the literacy rate of population was 70%. From disaster vulnerability point of view women children and are also a vulnerable group. The sex ratio was 879. The population between the age group of 0-6 was 14.17%. Corresponding figures for the above mentioned demographic parameters for the 2001 was not available.

Details of the economic activities of people were not available however, RITES (2004) mentions that the WFPR is 29% for the urban population (0.68 million people – of which Dehradun city accounts for the largest share being the biggest city in the state) of Dehradun District (the main workers were 92%).

The population of nearly 0.30 million is spread over 45 wards within the municipal boundary. The population is unevenly distributed over the area. Topography plays a major reason for this as well as, the process of city growth from core areas towards the fringe area. Population density of the wards
varies significantly as shown in the figure 3-3 in which is seen that certain wards such as Khurbura (the case study ward in the present study and encircled in figure 3-3), Jhanda Mohalla; Chukkuwala; Lunya Mohalla have population densities ranging from 280 persons per ha to 360 persons per ha. The distribution of population density reveals that highly dense areas (density more than 210 persons per hectare) exist in almost a pattern that forms spatially a ‘cross’ shape (with one lower left arm missing).

3.9. Builtup Structures

Housing in the city varies across the 45 wards in terms of number of stories. A brief summary of the total number and % of built-up structures is given in the table 3-1 below.

<table>
<thead>
<tr>
<th>Total Builtup Structures</th>
<th>Builtup Area (ha)</th>
<th>Ground Floor (G) Structures</th>
<th>G+1 Structures</th>
<th>G+2 Structures</th>
<th>G+3 Structures</th>
<th>More than G+3 Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
<td>No.</td>
</tr>
<tr>
<td></td>
<td>89888</td>
<td>696</td>
<td>61418</td>
<td>77</td>
<td>1771</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 3-1 Details of City Built up area and Floor wise Structures


It is seen from the above table (3-3) that 696 ha are built up. About 77 % of structures are ground floor structures and about 22 % of structures are ground plus one storied structures whereas, only (just over) 1 % structures are ground floor and two or more storied structures.

3.10. Building footprint map of Dehradun in GIS

The GIS based digitized Building footprint map for the city can be a useful input for a planning exercises both having area level as well as city wide coverage. This digitized map has been basically prepared for property taxation purpose and has the following information available:

<table>
<thead>
<tr>
<th>General Usage</th>
<th>Building Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster of Trees</td>
<td>Slum Area</td>
</tr>
<tr>
<td>Bridges</td>
<td>Traffic Island</td>
</tr>
<tr>
<td>Roads</td>
<td>Over Head Tank</td>
</tr>
<tr>
<td>Play Ground</td>
<td>Canal</td>
</tr>
<tr>
<td>Railway Station</td>
<td>River</td>
</tr>
<tr>
<td>Forest</td>
<td>Ponds</td>
</tr>
<tr>
<td>Open Space</td>
<td>Industrial</td>
</tr>
<tr>
<td>Park</td>
<td>Others</td>
</tr>
</tbody>
</table>

Source: MDDA, 2004

Table 3-2: Details available in the Building Footprint Map

3.11. Landuse

As of 1982, for which existing land use figures are available, the total area within municipal limits was about 3110 ha out of which 2398 ha (77 %) was developed. The remaining undeveloped area was in the form of streams, forests, agricultural area and vacant land. About 55 ha was under the category undefined. Dense patches of forests exist along the outer area of the city.
According to the Master Plan (1982-2001) prepared by the Town and Country Planning Department, the total developed area proposed for the year 2001 is 7045 ha. Of this, residential would comprise the major chuck (43 %) followed by water bodies (18 %) and land for Public and Semi Public use (12 %).

<table>
<thead>
<tr>
<th>#</th>
<th>Landuse</th>
<th>Existing Land use 1982</th>
<th>Proposed Land use 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Residential</td>
<td>1589</td>
<td>3002</td>
</tr>
<tr>
<td>2</td>
<td>Commercial</td>
<td>81</td>
<td>290</td>
</tr>
<tr>
<td>3</td>
<td>Industrial</td>
<td>113</td>
<td>350</td>
</tr>
<tr>
<td>4</td>
<td>Public &amp; Semi Public</td>
<td>801</td>
<td>833</td>
</tr>
<tr>
<td>5</td>
<td>Government &amp; Semi Government Offices</td>
<td>267</td>
<td>314</td>
</tr>
<tr>
<td>6</td>
<td>Parks, Open spaces &amp; Recreational Areas</td>
<td>156</td>
<td>226</td>
</tr>
<tr>
<td>7</td>
<td>Orchards &amp; Gardens</td>
<td>206</td>
<td>250</td>
</tr>
<tr>
<td>8</td>
<td>Circulation</td>
<td>203</td>
<td>400</td>
</tr>
<tr>
<td>9</td>
<td>Water Bodies</td>
<td>332</td>
<td>1296</td>
</tr>
<tr>
<td>10</td>
<td>Undefined Uses</td>
<td>55</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3803</td>
<td>7045</td>
</tr>
</tbody>
</table>

Note: Figures have been rounded off
Source: Master Plan of Dehradun (1982-2001)
Table 3-3: Existing Land use Pattern in Dehradun, 1982

### 3.11.1. Physical Growth Pattern of the City

Dehradun’s growth has been dominated by its topography. The main city areas lie between the two rivers (Bindal Rao and Rispana Rao) that flow from north to south. The road network system is radial and the major roads (or arterial roads) in the city are the Mussoorie Road, Dehradun-Rishikesh Road, Chakrata, Sahastradhara and Rajpur road. Along the Rajpur road (which acts as the main North-South corridor) and Sahastradhara road, ribbon development has taken place. Such type of development is also taking place and in fact expanding towards Haridwar road, Saharanpur road and Chakrata road.

According to the report of RITES (2004), the available width of the Saharanpur road is 25 m, that of Rajpur road is 20 m and Haridwar road is 25 m; whereas the actual ROW specified in the master plan is more (45 m for Saharanpur road and 30 m for Rajpur road and Haridwar road).

A new Master Plan for 2021 is presently under advanced stage of preparation stage and has details on the existing land use as well as the proposed land use. However, since this document is yet to be approved and published, such details on the cities land use were not available during the time of preparation of this report.

### 3.12. Infrastructure

This section discusses about the infrastructure in terms of water supply, power and transport; some of the details of which can provide indirectly useful insights into the city population profile.
3.12.1. Water Supply

Water source is mostly (about 80 %) from 42 tube wells that are over 100 m deep. Total water supplied is 77.4 MLD. The present average per capita consumption is well below 100 lpcd (Malhotra, 2004). Water supply is primarily done by two institutions i.e. Utranchal Jal Sansthan and the Cantonment Board. Water quantum from the Cantonment Board tube wells (9 in number) is 6 MLD. Water (17- 40 MLD) is also obtained from 25 private drilled tubewells – these are the second major source of water supply. The remaining water sources are the Mossy falls (14 MLD), Bindal Rao river (4 MLD), Rispana river head works (1 MLD) and Surface water in the Cantonment area (6 MLD). Thus, the total water supplied is 125.4 to 148.4 MLD.

The distribution mains (162 kms length) cover only 42 % of the city population. There are 17 Elevated Surface Reservoirs (ESR) in the city. One of the ESRs is located in the case study ward – Khudbura. The total number of water connections is 35,878 of which 92 % are domestic connections and slightly less than 3 % are commercial connections. The rest of the connections pertain to building construction (3 %), public taps (1 %) and about a quarter of a % of un-metered connections.

3.12.2. Power

The main source of energy to Dehradun and its adjoining area is met from the Hydel Power Stations; and; the Roorkee, Moradabad, Lucknow, Rishikesh node supplies the electricity to Dehradun and adjoining areas through the main grid installed in Mazra from where it is distributed by the Uttarakhand Power Corporation. The details of users and consumption of electricity within the municipal limits is as follows has been presented in table 3-4 and figure 3-4.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>99660</td>
<td>182.8</td>
<td>206.5</td>
<td>228.5</td>
<td>191.9</td>
</tr>
<tr>
<td>Commercial</td>
<td>18297</td>
<td>51.6</td>
<td>60.8</td>
<td>71.6</td>
<td>141.2</td>
</tr>
<tr>
<td>Industrial</td>
<td>504</td>
<td>17.0</td>
<td>17.1</td>
<td>18.4</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Source: Uttarakhand Power Corporation, 2004

Table 3-4 Details of users and consumption of electricity

It is seen from the table 3-4 that majority (84.1 %) of the connections are residential and very few (not even half a %) of the connections are for industrial use. This speaks volumes about the character of the city – being essentially a residential city. Also from the same table it is seen that there is a decline in electrical connections in the city during the year 2003-2004; the reasons for this need were not looked into as part of the present study as it is not directly part of the study objectives.
3.12.3. Transport

The transportation network is predominantly road based. The Dehradun Municipal Corporation maintains 305.14 Km whereas, 79 Km of road network in the cantonment area is maintained by the Cantonment Board. The Public Works Department maintains 15 Km stretch of State Highway and 75.6 Km. of Municipal Roads within the municipal limits. Majority of city roads are narrow and lesser in width ranging between 6 to 8 m.

The number of registered vehicles (according to Road Transport Office (RTO) figures) in the year 1994-1995 was 75043 whereas by the year 2003-2004 it was almost three times (viz.205569). About three fourths (81 %) of these registered vehicles are tow wheelers such as scooter, motor cycle, etc. and about 12 % are cars. In terms of vehicular growth, between the years 1994-2003, the average annual growth rate of registered vehicles has been about 15 %.

There is a registered fleet of 73 buses and 373 state carriageway buses for intracity and intercity travel. About 30 tongas’ is also plying on some routes in the City. Bicycles are also the integral part of the City’s traffic (with no separate lanes available for them) and constitute 10 to 15 % of the total traffic (RITES, 2004).

As per a RITES (2004) survey of the city’s road network based upon the carriage way width it was found that about 62 % of the road network length in the city are the intermediate lane roads, 25 % are 2 lane roads, 9 % are three lane roads and 4 % are four and above lane roads. Also, in terms of footpaths, only 4 % of the surveyed roads had footpaths which implies that majority of the pedestrians are using the road and the unpaved road curbs.

3.13. Development Planning and Disaster Management Institutions

For planning and regulatory purposes, there are two main Urban Local Bodies (ULBs) in Dehradun. One is the Mussorie Dehradun Development Authority (MDDA) and the second is the Dehradun Municipal Corporation (DMC).

3.13.1. Mussorie Dehradun Development Authority

The Mussorie Dehradun Development Authority (MDDA) was constituted in the year 1984 by the then state government of Uttar Pradesh with the objective to ensure planned development and check the degradation of natural environment.

3.13.2. Dehradun Municipal Corporation

The Dehradun Municipal Corporation is responsible for provision of civic amenities and facilities in the areas within the 45 wards. Besides it also performs functions such as collection of taxes, etc.
3.14. Issues plaguing the city

The city is transforming from being a paradise to pensioners and elite, to a city of multiple urban functions. For this reason, there is a tremendous pressure on land, utilities, services and facilities of the city, especially in the core area and around. Functionally, the city is now transforming from ‘Service city’ to ‘Capital city’ with a slight shift towards tertiary activities. The multifunctional character, thus, has contemplated many changes in the form and structure of the city (Ghildial, 2004).

As in the case of many developing country cities a number of urban development issues plague the city. The issues enlisted here below have become even more prominent with the city being given the status as the interim capital of Uttranchal state.

- High rates of urbanisation.
- Uncontrolled and haphazard development with illegal construction, sub-division of land in violation of the Master Plan (1982-2001) and encroachments on public lands and roads.
- Inadequate infrastructure that has not kept pace with the rapid urbanisation.
- Proliferation of slums at the low lands and at the beds of streams and natural ravines.
- Increase in motor vehicles coupled with marginal increase in road infrastructure and inadequate public transport system; leading to aggravated transportation and pollution problems.
- Absence of bypass road leading to directing of through goods traffic bound for the surrounding hilly regions right into the city.
- Non-engineered housing stock, making it vulnerable to natural hazards such as earthquakes.

3.15. Earthquakes in the past affecting Dehradun and the Doon Valley Region

The state of Uttranchal falls in the seismic Zone IV and V and as earlier mentioned, Dehradun falls in zone IV. The existence of Delhi-Haridwar ridge and its continuance right upto the Himalayas is a major reason for increasing the instability\textsuperscript{xxvi} of the state and surrounding regions.

The Uttranchal Himalaya has a well-known and recorded history where large magnitude earthquakes strike frequently. The entire area falls in a very high seismic vulnerability area. This region has already faced 36 major earthquakes in the last one and a half century. During the last century, the region has had 12 earthquakes of magnitude greater than 6.0 – on the Richter Scale (Ghildial, 2004). Table 3-5 below provides details about the earthquakes in the Uttranchal Himalayas. More details about the recent two earthquakes that had an impact on Dehradun city have been provided in Appendix I.
<table>
<thead>
<tr>
<th>Date</th>
<th>Intensity</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>1809</td>
<td>9.0</td>
<td>Badrinath</td>
</tr>
<tr>
<td>1 September, 1830</td>
<td>9.0</td>
<td>Gharwal</td>
</tr>
<tr>
<td>26 May, 1816</td>
<td>7.0</td>
<td>Gangotri</td>
</tr>
<tr>
<td>25 July, 1869</td>
<td>6.0</td>
<td>Nainital</td>
</tr>
<tr>
<td>28 October, 1916</td>
<td>7.5</td>
<td>Dharchula</td>
</tr>
<tr>
<td>28 October, 1937</td>
<td>8.0</td>
<td>Dehradun</td>
</tr>
<tr>
<td>27 July, 1966</td>
<td>6.3</td>
<td>Kapkot, Dharchula</td>
</tr>
<tr>
<td>28 August, 1968</td>
<td>7.0</td>
<td>Dharchula</td>
</tr>
<tr>
<td>29 July, 1980</td>
<td>6.5</td>
<td>Dharchula</td>
</tr>
<tr>
<td>20 October, 1991</td>
<td>6.6</td>
<td>Uttarkashi</td>
</tr>
<tr>
<td>29 March, 1999</td>
<td>6.8</td>
<td>Chamoli</td>
</tr>
</tbody>
</table>

Table 3-5: Earthquakes in Uttranchal Himalaya Region

Source: Ghildial (2004)

3.16. **Summary**

This chapter provided an overview of the city in terms of its demographics, land use, housing, infrastructure, development planning institutions, earthquakes in the past affecting Dehradun and the issues that plague the city. With this, the next chapter moves onto describing the data collection part of the study within which is also embedded a brief description of the case study ward.
4. Data Collection and Preparation

This chapter details out the actual raw data collection at the case study city and the preparation in terms of conversions to digital form of the study. Before embarking on the actual data collection procedure, in order to have a better understanding of what was to be done the framework of analysis was worked out (figure 4.1).

![Figure 4-1 Framework for Analysis]
4.1. Data Collection

Prior to the actual data collection in the field, the field work plan was prepared in order to plan in detail the work that was to be carried out. This included detailing out the information and data that were to be collected from organisations to be contacted. A variety of surveys were needed to be carried out in the study area. The Performa (for Household Activity Patterns, for Pedestrian and Traffic Surveys and for Building Surveys). The performa of the building survey was prepared based upon the researchers' experiences as well as while referring to sources such as the Vulnerability Atlas of India which provides the list of predominant roof and wall materials and; the questionnaire prepared by Prof. A.S. Arya. These Forma’s were tested in Enschede prior to the field visit. For example, all the above questionnaires were tested at ITC (on ITC student, buildings near ITC and Hengelosestraat for Traffic Survey). After incorporation of necessary changes (while keeping in mind that the questionnaires were applicable to the Indian situation) the questionnaires were further subjected to discussion. Later, during the commencement of field work in Dehradun, the questionnaires were again tested in three wards (Adhoiwal, Rajpur and Hathibharkhal) and many new answers to questions in the questionnaire that came up, were needed to be specified a code (for example, there was addition in the various activities that can be performed by a person and deletion of some of the modes of transport listed in the questionnaires). After finalisation of the questionnaires the same were tested in the case study ward. This brought about a further fine tuning to the questionnaire and led to the finalised questionnaires for the surveys (refer Appendix II to IV).

Secondary and Primary data were collected from various sources. In order to get preliminary knowledge of the city, the Guide Map was studied and places in the city were discussed about with people who had resided in Dehradun or visited the city. Such people were ITC faculty, researchers as well as students and people known to the researcher.

4.1.1. Secondary Data Collection

Secondary data was obtained by review of reports on Dehradun city and earthquakes at libraries of academic institutions and disaster management agencies. Also, information and data was obtained from the MDDA and DMMC at Dehradun.

4.1.2. Primary Data Collection

Visual observation and still as well as movie photography was an important means for obtaining ‘primary’ data. Hence, before commencement of actual surveys in the then ‘yet to be identified’ case study ward; a reconnaissance survey of the city was carried out. During the reconnaissance survey, the questionnaire testing was also carried out. The reconnaissance survey was the primary basis for selection of the case study ward.

Khudbur Ward (also refer figure 4-2) was selected as the case study ward. The rationale for the selection has been discussed hereafter.
Besides and during the reconnaissance survey, discussions were carried out with local communities (traders, residents of the city - particularly women, students, informal sector vendors), officials of both government offices (such as MDDA, DMC, Town Planning Department, Wadia Institute of Himalayan Geology (WIHG) as well as private offices – Architects, Civil Engineers) in the city with local knowledge. Communication with these organisations and individuals as well as personal perception (looking to the field situation as well as time availability) and discussion with the research supervisors made it finally possible to finally zero down on the case study ward (refer figure 4-2). It is important to note that information about the high amplification of the soil (based upon discussion with WIHG scientist) in the ward, which has a direct bearing on the effect of an earthquake to buildings and infrastructure, was also a prime factor for selection of the case study ward.

Figure 4-2 Ward boundaries (with case study ward encircled) over laid on the IKONOS, copyright Space Imaging, 2001

Khudbura, the case study ward, spans over an area 22.83 ha which is a third of a percent of the total city area. In terms of the population, the ward has one of the highest densities (with density of 280 persons per Hectare) in the city. As per a report by Ogra (2004), there are 1229 buildings in the case
study ward which implies that 1.36% of total city buildings lie in the ward and just in a third of a %’s area of the city under the jurisdiction of the municipal corporation.

On the whole the inner portions of the ward are dominated by housing and religious places with sporadic commercial development in the inner roads and alleys and somewhat that of a linear form along three of the outer boundaries of the ward. There are 5 schools in the ward, some of the famous ones lie on Tilak Road right at the top eastern corner of the ward. There is also a police station on Tilak road an ESR of 18000 MLD capacity within the ward.

However, along the eastern edge of the ward runs the busy Tilak road which is highly commercialised on both sides. On the south eastern tip of the ward, Tilak road at Hanuman Chowk meets other major roads (such as the Moti Bazar road) and from where, it proceeds in the south western direction and pools into the Jhanda Chowk where the famous ‘Jhande Maharaji’ Temple is situated (opposite which is a pond - two edges of the pond lie along the ward boundary). This temple witnesses the annual ‘Jhanda’ festival during which there is also a massive fair every March in which about 50,000 people from both within the city and ward as well as from outside the city (from as far as Punjab state) come and participate for a span of 5 days in March. Besides economic activities such as home based work, a number of milk dairies are also present in the ward, infact; the ward has one of the highest number of milk dairies as compared to other wards of the city. There is also an ice cream factory in the ward. Near to the western edge of the ward there are slums (known locally as ‘Maline Basti’), the University office and the girls school (which has a large play ground) that is run by the Trust of ‘Jhande Maharaji’. Beyond these developments is the Bindal Rao river.

There being no uniform address system in the ward and the buildings in the ward mostly having organic layout, made the survey work rather difficult. For example, there is an old and new house number for each house. Hence, it was difficult to survey based upon house numbering and looking to such field surveying difficulties, it was decided to subdivide the entire ward into blocks for the convenience of sampling (four the activity pattern surveys) as well as surveying.

**Sub-Division of the Ward into Blocks**

Based upon a rough analogue map of the ward, the road/lane network was demarcated during a rapid survey of the ward. The ward was then sub-divided into blocks (with the idea of facilitating survey work – one block usually was surrounded on all sides by roads and alleys - refer figure 4-3). In all, the entire ward was divided into 62 blocks. Based upon the predominant land uses in the block, the stratification of samples for the population activity pattern survey was carried out.
Figure 4-3 Division of Ward into Blocks (overlaid on IKONOS, copyright Space Imaging, 2001)
4.1.3. **Road Inventory and Surveys**

The knowledge gained from repeated visits to the ward, the still and movie photographs taken, the landuses observed and the impressions about business/quietness of the roads/lanes/alleys and along with the actual demarcation of the road network and blockages in this network formed the basis of the road, traffic and pedestrian volume survey.

![Figure 4-4 Traffic Survey (left) and Junctions Surveyed (right)](image)

A total of 51 Junctions and road sections were surveyed for traffic and pedestrian counts for durations ranging from an hour to 10 minutes during various times of the day for a working day as well as a Sunday. In order to save on time and manpower costs, each junction was surveyed for a period of less than an hour and then the team. It is to be noted that due to many directions from which traffic flows e.g. up and down, more than one person was required at one junction so as to get direction wise traffic and pedestrian counts. Thereafter, for the time after a particular survey, the surveyors moved onto the next junction. In this manner the entire day was utilized for survey of the road junctions. Moreover, for collection of the data on actual road characteristics and also for supplementing the later stage of road identification using remote sensing techniques (Brussel et.al), the road widths and materials were also noted down by way of actual measurement (of right-of-way (ROW) and carriage widths) and visual observation of the road material. Besides the number of vehicles and pedestrians, the actual number of people at the points/junctions of surveys was also noted.

Road network of the ward/city would have to be classified and based upon traffic volumes estimated from traffic study for the city (RITES, 2004) and primary survey of the area and also considering the land use of the surrounding/adjoining area, traffic and pedestrian volumes would have to be assigned.

Also, road network inventory (not street furniture and details of cross-section) survey in terms of the road width and road material was carried out. It is to be noted that the present study did not include the survey of on and off street parking; although it is possible that there are people who are sitting inside parked vehicles who may be affected in the eventuality of an earthquake (with perhaps buildings/walls falling on the vehicle as in the case of California).

The pedestrian survey helped in identifying the nature and quantum of pedestrian movement. Although in transportation surveys, pedestrian counts are used for other purposes (apart from the above); and assist in preparing up and down stream pedestrian canalisation schemes and calculations.
to assess need for PV^2 value (where P=Pedestrian and V=Vehicle) calculation for grade separation (i.e. subways or over bridges, etc.).

**Vehicle Modes**
The following vehicle modes are normally seen on the roads of the study area (also refer Appendix III).

![Vehicle Modes](image)

**Figure 4-5 Modes of travel and Road Scenario in Sector A**

The data obtained from the above survey is required for estimating the hourly traffic (and thus people in vehicles) and pedestrians on roads. Such data sets can be helpful in establishing population distribution on roads across various times (during the 24 hours on week days, Sundays and holidays). This will be an important input to the finally desired hourly population distribution layer in the study.

### 4.1.4. Building Surveys

Buildings house or have people residing or working in them, the number of people during each time of the day and night within each building vary based upon nature of use of the building and; the set indoor and outdoor routines of the people residing or working in them. The aim of the building survey was to map them as accurately as possible and collect details on physical characteristics and the number of families/shops housed within each of the buildings.

For building assessment, the questionnaire presented in Appendix III was used. In the field attempt was also made for taking the data digitally using mobile GIS with a palmtop (Ipaq - the IKONOS Imagery was loaded in the palmtop) and a GPS. However, while working with this system the procedure was slow as it took a long time to open and locate the position (due to the large file size of the base image). Moreover, the study area being 0.21 hectares and the image not clearly showing the building footprints sharp enough and the pixels breaking up; it was decided to take the building information in the traditional approach using survey forms. The survey was mainly done by survey teams formed in pairs of surveyors (with Civil Engineering background) and after an initial training imparted by the researcher (both on desk as well as in the field) on how to assess the individual buildings; the survey of buildings was carried out. Survey work of individual buildings was also
based on individual blocks. It is to be noted that this part of the work took up considerable amount of
the field work time.

4.1.4.1. Activity Pattern Surveys

This survey was part of the component on which major thrust is emphasized in the report. The
researcher carried out all the questionnaire surveys and discussions. Based upon various landuses and
keeping the block as the unit into consideration, 5% of the household/enterprise samples were
selected and surveyed.

4.1.5. Sampling

The sampling strategy involved stratified random sampling for the households/enterprise. This was in
combination with cluster (i.e. block wise) sampling procedures. The basic sampling unit was the
household/enterprise. Stratifications were in terms of the use of the building use viz. for living,
business, etc. This was necessary so as to obtain representative samples from the study area.

Every tenth household/enterprise was surveyed – however, this was often not based upon a linear
fashion as sometimes ten houses were not linearly arranged in terms of settlement layout due to some
parts of the study having a very organic character of built-form layout.

Major factors that led to the selection of the unit for the survey was the willingness of the respondent/s to
divulge information about themselves and others in the unit as well as spending time sufficient for the
survey.

In a building, a household/enterprise was contacted and, in terms of the choice of the respondent – if
possible all who were present were asked about their activities (routines). In case this was not possible,
then the household head or household head’s spouse was asked questions – in fact, in a majority of the
samples, they became the prime respondents.

Figure 4-6 Samples Selected for Activity Pattern Survey

As seen from Appendix IV, the questionnaire was not one with instructions for the respondents to list
out their activities, and instead it was one in which the surveyor noted down the information (also
refer figure 4-7 below).
Initially, the demographic characteristics of the household/enterprise were noted down followed by a detailed discussion about their routine (activities) of a member on a typical day (implying to 24 hour) in their present lives. Particular attention was given to know the activities of each member during a week day, a Sunday as well as on a typical holiday – both national as well as festival holidays. Often it was noticed that the prime respondents (or other members of the unit) were hesitant to divulge such information – since according to them, it has larger ramifications on the security of the unit/house (implying to robberies) as well as the unit members.

Figure 4-7 Household Activity Pattern Survey

4.1.6. Collection of Other Information

Apart from the above activity pattern survey and also during the same; simultaneous information about the various holidays that are observed in the city were also noted down. The figure 4-8 gives a general list of holidays under various categories.

4.2. Holidays Observed in the City

The whole year (considering a non leap year) can as such be divided into the following type of days. That is about 52 Sundays and the rest are weekdays. Within both of these categories fall the holidays. These have been discussed briefly hereafter. According to the Shops and Establishments Act, there are seven registered Holidays – these are the days when many offices and establishments as well as non-petty item shops (except for during festivals such as Diwali – when most of the shops are open) are closed in the city. However, most shops do remain closed on festivals such as Holi. There are in all about 15 National Holidays and certain religious holidays (pertaining to Christianity, Hinduism, Islam, Jainism, Sikhism, etc.) overlap with these national holidays for example Id, Christmas, Diwali, etc. There are community/religion specific as well as location specific holidays also. These have not been elaborated upon, however, as an example of a place specific and religion specific holiday, in the case study ward; during the Jhande Saheb’s festival, the chain of schools (about 500 in all in the country) run by the Jhanda Darbar remain closed. More details of the same are discussed in the next chapter. Also, it is possible that many of these holidays overlap with a Sunday. Apart from all these different holiday types, it is possible that there is a holiday simply because a Bandh (Closure) has been declared by a Student’s Association, a political party, etc. Such information is very useful since the activities of people are directly dependent upon these aspects.
4.2.1. Community Based Organisation

Information on Ward level Community Based Organisation active in the study area has been given in the following section.

4.2.1.1. Civil Defence

The Civil Defence is a semi government organisation operating under the umbrella of the Ministry of Home Affairs, Government of India. The organisation operates under the Home Guards office in Dehradun. Information on the Civil Defence organisation was obtained through many rounds of discussions with the organisation’s Sector Wardens and Post Wardens (present as well as ex).

The Civil Defence Organisation operates right up to the community level. The basic purpose of formation of this organisation was preparedness of the local community against any enemy attack. Dehradun is a major military head quarter and a sensitive base for the enemy to strike by air (that may lead to fire and thus a requirement for rescue operations and first aid would arise) and hence this city (the only one in Uttarakhand, 17 cities and towns in the neighbouring state of Uttar Pradesh and in all, 171 cities and towns through the country) have the Civil Defence Organisation operating in them under the umbrella of the Ministry of Home Affairs situated in New Delhi.

Presently the organisation provides thirteen different services which include providing training - to various organisations, factories, government offices, private offices, schools and colleges - on how to undertake preparedness measures in case an air attack takes place.
In Dehradun, every ward, has representatives of the organisation from within the community. Each ward has been divided into sectors; for example the case study ward (Khudbura) has been divided into five sectors viz. A to E (also refer figure 4-9). Each sector has two functioning representatives of the ward known as ‘Sector Wardens’. Besides, there is also a Reserve Warden. Thus, in all, the ward has 10 Sector Wardens and 5 Reserve Wardens. The Post Warden is overall incharge of all the sectors and Wardens. Infact, the entire city has been divided into twenty sub-units named as Posts. Each post may be a part of one or more ward. Approximately a population of 10,000 people are covered in one post (i.e. one Sector Warden is appointed per 1000 population). Thus, in the case of Khudbura, the five sectors not only cover this ward, but in fact, also cover a part of the adjoining ward. The Sector and Post Wardens work on voluntary basis and are provided training in Warden Services from time to time by the Home Gaurds office at Dehradun. It is to be noted that five of the Sector Wardens are women amongst whom one is a Homeopathic doctor and two teachers and one who has a home based trading business. At the city level, for a population of 100,000; there are 10 Post Wardens, 3 Reserve Post Wardens and 3 Deputy Post Wardens.

After receiving training from the Home Gaurds office, the Sector wardens in-turn, impart the training to selected representatives from the population. For example they select 10 people per 1000 population and provide fire fight training programme to them. Thus, for every 100 persons, there is a trained fire fighter. Here the assumption is that the fire may be caused by a gas leakage or some kind of bomb. Also, for every 750 persons, the Assistant Deputy Controller provides other training programmes – thus four persons from the community in ever sector receive the training. Besides the...
24 people mentioned per sector having attended such training programmes, as a reserve manpower, 6 persons (i.e. 25% of trainees) are also trained for similar training programmes.

In terms of information that the Sector Wardens maintain (and submit to the Home Guards office) these include an updated enumeration of each household per sector, list of officials of the Civil Defence organisation, main places in the sector\textsuperscript{xxxiv}, important people living within the sectors and also important facilities (such as police station), name of members in the Warden Service. The following are the details that are mentioned in the sector wise registers maintained manually and updated regularly (refer table 4-1).

<table>
<thead>
<tr>
<th>House #</th>
<th>Area location</th>
<th>Name of Person</th>
<th># of Males</th>
<th># of Female Members</th>
<th>Age of Males Members</th>
<th>Age of Females Members</th>
<th>Marital Status</th>
<th>Any Pets/ Cattle</th>
<th>Main Occupation of Household head and Members</th>
<th>Owner/ Rented House</th>
<th>Presence of Explosive Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1 Household Details Maintained in the Civil Defense Register

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Males (%)</th>
<th>Females (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;1</td>
<td>0.97</td>
<td>0.68</td>
</tr>
<tr>
<td>1-3</td>
<td>2.74</td>
<td>2.72</td>
</tr>
<tr>
<td>4-5</td>
<td>2.42</td>
<td>3.40</td>
</tr>
<tr>
<td>6-12</td>
<td>10.97</td>
<td>12.41</td>
</tr>
<tr>
<td>13-17</td>
<td>9.03</td>
<td>9.01</td>
</tr>
<tr>
<td>18-35</td>
<td>29.68</td>
<td>28.23</td>
</tr>
<tr>
<td>36-60</td>
<td>30.97</td>
<td>31.97</td>
</tr>
<tr>
<td>61-70</td>
<td>7.74</td>
<td>6.80</td>
</tr>
<tr>
<td>71-85</td>
<td>5.00</td>
<td>4.42</td>
</tr>
<tr>
<td>&gt;86</td>
<td>0.48</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 4-2 Age Sex Distribution

The age sex group distribution depicts the fact that a majority (about 60 % i.e. 60.65 in case of males and 60.20 % in case of females) of population of sector A falls within the working age group (18-60 years). About 7 % (i.e. 6.61 % in case of males and 7.14 % in case of females) fall within the most vulnerable age bracket. It also reinforces the point that females are more vulnerable as compared to males in terms of disasters.

The total population of sector A is 1193 and the sex ratio\textsuperscript{xxxv} is 1022. There are 205 households and the average household size is 5.49. Apart from these households, there are three schools (Silver Bells School, Har Prashad Model School and City Board School). These schools have further sub divisions based upon level of education (primary, secondary, etc.) and gender. The first two schools are run by private sector whereas the city Board School of run by the Municipal Corporation. There are also two dairies operated by local residents and in which are 17 cows and 33 buffaloes. Apart from these cattle, the some of the households in the sector have pet dogs, cats, birds – the number of pet dogs (18
numbers) is recorded. It is pertinent to note that besides these animals there are stray animals (such as dogs, cows, pigs, etc.) roaming in the area.

The register is meticulously maintained and any incoming or outgoing family in the area, incoming or outgoing (for example due to marriage of a girl) resident leads to the swift updating of the register. While updating, clear signatures and stamp of date of updating is noted on the particular page of the register for further reference.

There are many shops and offices also in sector A, however, details of persons working in these enterprises has not been recorded by the local CBO.

The above data is an important source of information for many purposes (such as vulnerability analysis). Since the community based organisation representatives belong intrinsically from within the community, their local knowledge base is extremely strong and relevant. It appears to be an important and potential source of database as well as a community based mechanism for disaster risk management. However, this leads to the requirement of policy level interventions right at the Central Government level.

4.2.1.2. Community Based Workshop

A Community Based workshop with population of sector A (based upon Civil Defence’s classification of the ward) was carried out in order to have the community mapping their risk and resources – as perceived by them in their surroundings. A questionnaire was prepared to have a discussion about the level of awareness amongst the community. The study area analogue map was shown to the community members for this exercise. The Ward residents (particularly those residing /working in Sector A) were contacted directly as well as through the Community Based Organisation Representatives (i.e. Civil Defence Sector Wardens). Finally the communities views on disaster awareness and reduction were obtained along with a risks and resources (refer table 4-3) map prepared by them according to their perception.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak Buildings</td>
<td>Open grounds</td>
</tr>
<tr>
<td>Densely Populated Area</td>
<td>Schools</td>
</tr>
<tr>
<td>Income wise poor people</td>
<td>Clinics/Hospitals</td>
</tr>
<tr>
<td>Low lying area</td>
<td>Public Buildings</td>
</tr>
<tr>
<td>Petrol Pump (due to risk of fire)</td>
<td>Police Station</td>
</tr>
<tr>
<td>Industrial Location</td>
<td>Collector/Commissioners Office</td>
</tr>
<tr>
<td>Sensitive areas (due to communal unrest)</td>
<td>NGOs</td>
</tr>
</tbody>
</table>

Table 4-3 List of Risks and Resources for Community Based Mapping

Source: Based upon UNDP-UEVRP’s risk and resource mapping method
4.3. Data Preparation

First of all, all the questionnaires were sorted out block wise taking into consideration the building serial order (marked during building survey and which was used as the primary field level key to identify) a house (and thus a household/enterprise within that building). For the road surveys, the questionnaires were arranged according to junction/point wise and thereafter time wise and date wise.

Subsequently, the different variables under each of the questionnaires were enlisted and a database schema (refer 4-11 Appendix V, VI, VIII, XI and XII) was prepared showing the relationships, the primary keys for each of the entities and their attributes.

Figure 4-11 Entity Relationship Diagram

Note: Also refer Appendix V for list of attributes
4.3.1. Change of Projection System of the IKONOS Imagery

High Resolution Satellite Imagery – from the One-Meter resolution IKONOS sensor provided substantial amount of geospatial information content that was especially required to generate a map pertaining to the road networks, water bodies etc. for the case study ward. Since the IKONOS imagery (tiles infact that had to be first arranged into a mosaic in Erdas Imagine 8.7) pertained to the year 2001, the same was primarily used as a reference base map. In raster form the pixel size was also of one meter and it was observed that at a certain resolution, these pixel were breaking up, thus clear recognition of roads as well as building footprints proved to be a major bottleneck.

One observes that while IKONOS itself is a powerful source of obtaining data on roads, etc. it is insufficient for carrying out a study as that of the present nature where details upto individual buildings and roads widths are to be obtained. Hence, considerable ground truthing had to be done for obtaining such information. This requirement was fulfilled while doing extensive individual building surveys and the road traffic and pedestrian surveys. Guragian (2004) categorically mentions that to create an individual building footprint layer and also to observe the building characteristics like height and type of the building large scale aerial photographs are required.

For further analysis and modelling, an important aspect to note was the transformation of the projection system from UTM, WGS84 to Polyconic. The following table 4-4 provides the projection details. It is to be noted that for further work on the city and/or for collating the work of other researchers on geological or other aspects, the differences arising as a consequence of importing data from one GIS programme to another as a consequence of change in the projection system will have to be dealt with at the outset in order to ensure data exchange in a convenient format. For example, in case of ArcGIS 9.0, while importing an .img file (i.e. Erdas Imagine file), the Ellipsoid of Everest 1830 is automatically selected by the programme, a reason for this may be due to non availability of an Ellipsoid named ‘Everest’ and also perhaps due to the Everest 1830 being the first ‘Everest’ related Ellipsoid on the soft wares list of Ellipsoids.

Also, if we compare the Everest 1830 and the Everest 1856, we find that there is a shift of 0.7 meters; such a difference would have a significant impact on a study such as the present one where peoples activities (in terms of outdoor activities and vehicular movement) and buildings have to be studied. This also highlights the fact and importance of choosing the appropriate and applicable Datum.

<table>
<thead>
<tr>
<th>#</th>
<th>Particulars</th>
<th>Old Projection</th>
<th>New Projection System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Projection</td>
<td>UTM, WGS84</td>
<td>Polyconic</td>
</tr>
<tr>
<td>2</td>
<td>Spheroid/Ellipsoid</td>
<td>D_WGS_1984</td>
<td>Everest</td>
</tr>
<tr>
<td>3</td>
<td>Datum</td>
<td></td>
<td>Everest*</td>
</tr>
<tr>
<td>4</td>
<td>Latitude</td>
<td>78° 00</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Longitude</td>
<td>32° 15</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>False Easting</td>
<td>500000</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>False Northing</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: * In Erdas Imagine Version the Spheroid/Ellipsoid was Everest, whereas while importing the IKONOS imagery in ArcGIS 9.0, the Spheroid is Everest 1830.

Source: Discussions with IIRS MSc students and ITC Faculty

Table 4-4 Projection System Details
4.4. Geo referencing of Individual Field survey analogue maps

After having transformed the One-Meter resolution IKONOS sensor imagery to the new projection system (Polyconic), each of the field survey maps (with buildings marked on them blockwise) were geo referenced using at least seven ground control points in Erdas Imagine 8.7 Version (refer table 4-12 below). A total control point error of less than 0.005 was obtained for each of the maps. Also, the newly created geo referenced map files was ‘Swiped’ against the imagery in order to ensure satisfactory overlap. The newly created ‘.img’ raster files were used as a base for digitization of individual buildings. In this manner, for each block a geo referenced raster layer was created and buildings foot prints were digitised.

Figure 4-12 Geo referencing Model

4.4.1. Digitisation

Digitisation of roads and buildings and creation of junctions had to be carried out in order to depict the field data collected spatially.

Figure 4-13 Digitisation of Roads and Buildings (features overlaid on IKONOS, copyright Space Imaging, 2001)
4.4.1.1. Digitisation of Roads

People mobile on roads are likely to be as such at lower risk (than people inside buildings). However, inspite of the short duration of their presence on the roads, the sheer volume of people using the roads – especially major roads at certain time periods (such as at rush hours) makes the roads a necessary feature to survey for knowing the counts of traffic, stationery vending and selling stalls and pedestrian volumes.

Based upon the IKONOS imagery as well as field area survey map, the roads were digitised along the centre lines to create a shape file for roads of the case study ward. The roads were given appropriate widths based upon ‘buffering’ function (with measurements based upon field survey) after which each road was assigned the attribute pertaining to surface material. It was observed that many of the roads were blocked by residents for use of the space (meant for road) as their private compound. This is can be an adversely affecting factor while planning escape routes in case of a disaster, if appropriate ground truthing of the area is not carried out and only satellite imagery is used for planning.

4.4.1.2. Digitisation of Buildings

Based upon field level sketches of the buildings, the building footprints were digitised in Arc GIS 9.0. Particular care was taken to ensure that the auto complete polygon option was kept active so as to avoid duplication of common wall boundaries of buildings. Based upon the building IDs given during field survey of individual buildings, the unique identifier was given to each building in each block.

![Digitised Buildings of Sector A](image)

Figure 4-14 Digitised Buildings of Sector A

4.4.1.3. Creation of Junctions

The road shape file was converted into coverage (in ARC GIS 9.0), the coverage was subsequently cleaned (and built) in Arc Info. After this step, a new geodatabase was created and after importing the cleaned coverage, a new geometric network was built using the nodes of coverage). In the geometric network, complex edges were not specified and a tolerance of 0.002 was given. Creation of a geometric network led to the creation of junctions at the intersection of arcs.

However, not each junction was required to be represented in terms of traffic and pedestrian volumes since not all junctions depicted in the layer were surveyed for the traffic and pedestrian volumes.
Hence the layer (junctions file) was copied and the data on traffic and pedestrian volumes for the junctions surveyed was entered in the attribute table of road section.

4.5. Summary

This chapter discussed the data collection and the data preparation stages of the study and also provided insight into the case study ward and the community based organisation that is involved with the community on a day to day basis. In absence of any digital information, considerable time of the study was invested in these stages and the next chapter outlines the analysis related to buildings vulnerability.
5. Building Vulnerability Assessment

5.1. Introduction

This chapter looks into the assessment of building vulnerability aspect for two essential reasons. Firstly, such an assessment feeds into the population vulnerability exercise and secondly, determining the building vulnerability on a building-to-building basis forms a sound base for basic disaster preparedness and mitigation steps such as retrofitting of vulnerable buildings – such steps can significantly decrease the population (both within and outside buildings) vulnerability to a great extent. Building vulnerability assessment for a part (one sector - A) of the case study ward has been taken up since the total (as of October 2004) population for sector A is known based upon the CBO records and this will be a necessary input for the analysis described in the next chapter. The buildings in the case study ward are spread over five sectors (the entire city has been sub divided into sectors as demarcated by the Civil Defence organisations for their operations and house to house population is available with this organisation on a sector by sector basis). One sector for the analysis has been taken up with the idea of establishing a process of building vulnerability assessment which can be replicated not only for the entire ward but also for all the city buildings (also refer Appendix V and VI). The figure 5-1 below gives an overview of the building occupancies of the entire ward, and the sub division of the same sector wise.

![Figure 5-1 Building Occupancy in the Khudbura Ward (sector A earmarked by red rectangle) and all (5) sector boundaries shown in inset two dimensional figure](image-url)
Building occupancies for the entire area (based upon the individual building survey) has been presented in the table 5-1. It is seen that just over three fourths of the buildings have residential occupancies. Schools form about 2% of the building occupancies whereas the rest (with the exception of the building in the water body) and the ESR are the buildings having mixed occupancies (residential, commercially, clinics, etc.).

### Table 5-1 Building Occupancies in Case Study Ward

<table>
<thead>
<tr>
<th>#</th>
<th>Building Occupancy</th>
<th># of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Residential</td>
<td>794</td>
<td>770</td>
</tr>
<tr>
<td>2</td>
<td>Commercial</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Residential + Commercial</td>
<td>138</td>
<td>130</td>
</tr>
<tr>
<td>4</td>
<td>Clinic</td>
<td>5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>5</td>
<td>Industrial</td>
<td>4</td>
<td>&lt;1</td>
</tr>
<tr>
<td>6</td>
<td>School</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Office (Private Sector)</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>8</td>
<td>Other</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Residential + School</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Residential + Office (Government)</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>11</td>
<td>Residential + Office (Private Sector)</td>
<td>3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>12</td>
<td>Residential + Office</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>13</td>
<td>Commercial + Clinic</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>14</td>
<td>Commercial + Office</td>
<td>4</td>
<td>&lt;1</td>
</tr>
<tr>
<td>15</td>
<td>Residential + Commercial + Clinic</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>16</td>
<td>Residential + Commercial + Office (Private Sector)</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>17</td>
<td>Water Body</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>18</td>
<td>Office (Private Sector) + Others</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1028</td>
<td>100</td>
</tr>
</tbody>
</table>

5.2. Buildings in the Study Area

Based upon field survey data collected for individual buildings in terms of the general characteristics such as occupancy class, age, shape, building materials of roof, wall and floor and building condition; this section presents the profile of buildings located in Sector A. In all, there are 159 buildings in this sector A (refer table 5-1). Just under half (46%) of these buildings are detached with many of them having inappropriate separation distance i.e. the separation distance between two buildings being less than 4% of the building heights - as per a thumb rule provided be FEMA. Inappropriate separation distance could adversely affect buildings even though they may be strong enough, this is due to the fact that adjoining weak buildings could lead to the collapse of the neighbouring buildings as a result of a type of ‘domino’ effect. The total built up area of the 159 buildings is 30,309 square metres and the total area under Sector A is 47,293 square metres, thus, for every square metre of land in the sector, 0.64 metres of the same is built up.

![Figure 5-2 Separation Distance between buildings](image)
5.2.1. Building Occupancy Classes

The building occupancy class or use is representative of the general land use characteristic of any area. The present study is predominantly in a residential area and hence most of the buildings (58%) are residential. Almost all (97%) of the buildings are located on a gentle slope – as observed during the field visit) and, the remaining (totalling to 8 buildings) are located on a steep slope. All the buildings except one (an Elevated Surface Reservoir (ESR)) which is dangerously located in the city board school compound – also refer figure 5-1 are load bearing. Except this ESR, the distribution of buildings by the number of stories is almost equal - the % of ground floor structures is 55% and those with an additional floor (i.e. ground floor plus one floor) is almost 45%.

The building occupancy in sector A as revealed from the field survey has been represented in the figure 5-1. About 60% of the buildings have exclusively residential occupancy and 20% have commercial or mixed (i.e. residential cum other uses) occupancy. It is observed that buildings having commercial and mixed occupancy are situated mainly along the road network. Also, a significant point to note is that more than nearly one tenth of the buildings are schools, which is atypical to the characteristics of the city of Dehradun known often as a ‘City of Schools’.

Figure 5-3 Elevated Surface Reservoir in the case study ward

5.2.1.1. Specific Building Occupancy

Besides knowing in terms of the general building occupancy; details of specific building occupancy were also noted and the results give particular insight into the actual occupancy of the buildings especially those having mixed and other purposes. This was done in order to facilitate the analysis of population in terms of their activities – that are to a great extent dependent upon the occupancy class of the buildings in which they reside/work/study.

Figure 5-5 depicts specific building occupancies such as cattle sheds (of dairies), buildings for public purposes, coaching centres (where many students – mostly from outside the ward come to study), religious buildings, community buildings, etc. Also, the variety of uses that many (18 in number) of the individual buildings are put to is amply evident. For example, a building (encircled) is used as a home, cattle shed (dairy) as well as a counter for selling the milk.

Figure 5-4 Dairy (with selling outlet) on ground floor, Residence on first floor
### Legend

Specific Building Occupancy

- Residential
- Commercial
- Residential + Shops
- Residential + Office
- Office
- Godown
- Cattle Shed
- Vacant
- Factory
- School
- Coaching Centre
- Other usage (Water Tank)
- Shop + Godown
- Residential + Cattle Shed
- Residential + School
- Residential + Home-based Work
- Shop + Coaching Centre
- Residential + Shop + Vacant
- Residential + Shop + Coaching Centre
- Residential + General Store (Shop) + Games Shop
- Residential + Office + Home-based Work
- Religious Place + Community Space
- Khubura Ward Buildings
- Roads

### Figure 5-5 Specific Building Occupancy

<table>
<thead>
<tr>
<th>Specific Building Occupancy</th>
<th>Number of Buildings</th>
<th>% Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>92</td>
<td>57.9</td>
</tr>
<tr>
<td>Residential + Shops</td>
<td>16</td>
<td>10.1</td>
</tr>
<tr>
<td>Residential + Office</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>Residential + Cattle Shed</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Residential + School</td>
<td>5</td>
<td>3.1</td>
</tr>
<tr>
<td>Residential + Home-based Work</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Residential + Shop + Vacant</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Residential + Shop + Coaching Centre</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Residential +Office + Home-based Work</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Residential + General Store (Shop) +Games Shop</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Commercial</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>Shop + Godown</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Godown</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>Office</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>Industrial</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>Cattle Shed</td>
<td>1</td>
<td>.6</td>
</tr>
<tr>
<td>Vacant</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>School</td>
<td>10</td>
<td>6.3</td>
</tr>
<tr>
<td>Coaching Centre</td>
<td>5</td>
<td>3.1</td>
</tr>
<tr>
<td>Shop + Coaching Centre</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Religious Place + Community Space</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Other usage (Water Tank)</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Total</td>
<td>159</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### Table 5-2 Specific Building Occupancy in Sector A

Age distribution of Buildings
The case study ward is the oldest ward in the city – in fact it is from here that the city was established. Hence many buildings are quite old (i.e. greater than 200 years) and very few are newly constructed due to lack of space for construction. Sector A is one edge of the ward and does not house the oldest buildings in the ward. The age group wise distribution for the buildings in Sector A are presented in the Table 5-3 and figure 5-6.

It is seen that nearly half (46.5%) of the buildings are between the age of 61 to 80 years. Considering the average economic life (about 60 years) of buildings in the local context; it can be said that about 75% of the buildings in the sector A have already outlived their usual life age.

<table>
<thead>
<tr>
<th>Building Age Classes</th>
<th>Number of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>12</td>
<td>7.5</td>
</tr>
<tr>
<td>6-20</td>
<td>19</td>
<td>11.9</td>
</tr>
<tr>
<td>21-40</td>
<td>33</td>
<td>20.8</td>
</tr>
<tr>
<td>41-60</td>
<td>11</td>
<td>6.9</td>
</tr>
<tr>
<td>61-80</td>
<td>74</td>
<td>46.5</td>
</tr>
<tr>
<td>81-150</td>
<td>10</td>
<td>6.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>159</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Table 5-3 Age distribution (# & %) of buildings in Sector A

### 5.2.2. Building Configuration (Shape)

The buildings are of various shapes and about two thirds (64.8%) are of regular shape (i.e. either square or rectangular with length being less than or equal to three times the breadth). As observed during the field visit, majority of these buildings are also regular in elevation. The irregular buildings (those having their length and breadth ratio higher than 3) comprised the remaining one third of the buildings (also refer appendix III).

<table>
<thead>
<tr>
<th>Building Shapes</th>
<th># of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>3</td>
<td>1.9</td>
</tr>
<tr>
<td>Rectangular (L ≤ 3B)</td>
<td>100</td>
<td>62.9</td>
</tr>
<tr>
<td>Narrow Rectangular (L &gt; 3B)</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>T-Shaped Building</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>L-Shaped Building</td>
<td>32</td>
<td>20.1</td>
</tr>
<tr>
<td>U-Shaped Building</td>
<td>10</td>
<td>6.3</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
<td>5.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>159</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Table 5-4 Building Shapes in Sector A
5.2.3. Building Materials

Materials of the buildings were particularly observed during field survey since the damage matrices (discussed later in section 5.2). The material of the three most important buildings elements viz. roof, walls and floor was noted. Results of the observed building materials has been presented in this section.

5.2.3.1. Roof

<table>
<thead>
<tr>
<th>Building Roof Type</th>
<th># of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced Brick Concrete (RBC)</td>
<td>107</td>
<td>67</td>
</tr>
<tr>
<td>Reinforced Cement Concrete (RCC)</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>Stone in Cement</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Brick in Cement</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Tin</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Reinforced Brick Concrete (RBC) + (RCC)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Reinforced Brick + Tin/G.I.</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Tin/G.I. + Wood</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Tin/G.I. + Thatch</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Thatch + Plastic</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total</td>
<td>159</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 5-5 Roof Types in Sector A

It is seen that about two thirds (67.3 %) of the buildings have reinforced brick concrete (RB) roof (also refer figure 5-7) and 23 % have RCC roofs. RBC roofs were more in vogue as a roof material about 30 years ago, after which RCC roofs also started being constructed. Nonetheless, the practice of constructing RBC roofs is still being continued since it is cheaper roof form as compared to RCC roofs. RBC roofs are more vulnerable to damage as compared to RCC roofs due to lesser homogeneity existing between the roof materials as compared to RCC. The rest of the buildings have other roof material such as Tin/G.I. sheets, thatch, tarpaulin, plastic, etc.
5.2.3.2. Wall Material

The figure 5-8 gives the wall material wise layout of the buildings in sector A. It is seen that the majority of the buildings have brick in lime as wall material.

<table>
<thead>
<tr>
<th>Building Wall Material</th>
<th>Number of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>None* (M S Sections)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Stone in Mud</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Stone in Lime</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Brick in Mud</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Brick in Lime</td>
<td>101</td>
<td>64</td>
</tr>
<tr>
<td>Brick in Cement</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>Stone in Lime and Brick in Lime</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Stone in Lime and Other material</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Brick in Lime and Brick in Cement</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>159</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 5-6 Building Wall Material in Sector A

Note: *: Three buildings/structures have MS sections as stilts for walls. These structures are used for parking and as weather shades.

The most commonly observed wall material is brick masonry in lime. The practice of wall construction in such type of masonry was highly prevalent about 40 years ago, about one thirds (64 %) of the buildings have such walls. Field Stone Masonry buildings comprise about 11 % of the building stock. There are very few buildings (in fact only 2 buildings) that have walls of brick in mud. One of the two buildings is used as a residence by the caretaker (living with his family) of a vacant piece of land and the other is used to store household items.

Figure 5-8 Buildings Wall Materials wise in Sector A
5.2.3.3. Floor

<table>
<thead>
<tr>
<th>Building Floor Material</th>
<th>Number of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>101</td>
<td>64</td>
</tr>
<tr>
<td>Mosaic</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>Kutchha - mud</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Brick</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Stone</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>PCC + Mosaic</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>PCC Kutchha - mud</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>PCC + Brick</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>PCC + Stone</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mosaic + Stone</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total</td>
<td>159</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 5-7 Floor Material of Buildings in Sector A

The floor material is often a sound indicator of the affordability levels of people – for example a building with mosaic tiles as flooring material would reflect a better economic position of the owner as compared to a building with flooring material of plain cement concrete (PCC). PCC as floor material is observed in 64 % of the buildings followed by about 20 % of buildings having mosaic tiles as floor material. This was followed by a combination of floor materials the highest being that of PCC flooring in about 7 % of the buildings.

5.2.4. Building Condition

During the building survey, the details of building condition was also noted (base upon the surveyors opinion – Such opinion was purely as per visual observation. Data on building condition of the 159 buildings revealed that 18.9 % of the buildings are in good condition, 66 % in the fair condition and a significant 15.1 % (24 buildings) are in poor condition.

5.2.4.1. Visible Cracks

One fourth (23 %) of the buildings did not have any ‘apparently’ visible cracks whereas the remaining buildings had cracks of one type or a combination thereof (i.e. horizontal, diagonal, vertical) and separation of walls at T and L junctions.

5.2.4.2. Condition of Walls

Dampness was observed in majority of the walls (47 %) of the buildings surveyed and nearly 20 % of the walls had good condition i.e. there were no signs of dampness, delamination and bulging. In 4 buildings, tilting of walls was observed which is very serious particularly from the safety point of view of people living within and near these buildings, as well as those moving on foot or vehicles from near these buildings.
5.3. Building Vulnerability Assessment

In this section building vulnerability assessment has been done in the context of causal factors such as earthquakes although the city does lie on a gently sloping terrain at the foot hills of the Himalayan ranges and parts (such as in the northern edge of the city) are also susceptible to landslides.

5.3.1. Preparation of Damage Matrices

Damage Matrices for different types of buildings (depending upon their wall material) in Dehradun (based upon vulnerability curves derived by Prof.A.S.Arya from data pertaining to various buildings types prevalent in India and have been adapted by NSET, Nepal are presented hereafter. The values in the matrices indicate the range of % of buildings of the same type of materials that are likely to collapse or have partial damage, based upon historical earthquake damage inventories. Thus, these are the generalised values and cannot be used to describe the probability of collapse for individual buildings. As these may have particular characteristics which make them different from the average type of buildings with the same construction type.

In the present analysis, wall material is used to decipher the type of building for which different levels of probability of damage patterns exist under earthquakes of different intensities.
The table 5-9 provides for each building type the values pertaining to the probability of damage patterns (total collapse and partial damage) along with the number and % of building. It is to be noted that these matrices only indicate the maximum and minimum probability under each damage state for individual buildings for various intensities. Also, that probable damage patterns for buildings with brick in lime type of wall material (found extensively in the study area) has been considered for the present study similar to that of Brick in Mud (BMW) category. However, what is not known from such matrices is the spatial location of the buildings under each damage state. Spatial location of the identified buildings that have a probability of damage in the event of an earthquake has been further discussed in the next sub section.

<table>
<thead>
<tr>
<th>Building type</th>
<th>MMI</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PGA (% g)</td>
<td>5-10</td>
<td>10-20</td>
<td>20-35</td>
<td>&gt;35</td>
</tr>
<tr>
<td>Adobe+ Field</td>
<td>Total Collapse</td>
<td>2-10</td>
<td>10-35</td>
<td>35-55</td>
<td>55-72</td>
</tr>
<tr>
<td>Stone Masonry</td>
<td>Partial Damage</td>
<td>5-15</td>
<td>15-35</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Buildings**</td>
<td>Brick in Mud (BM)</td>
<td>Total Collapse</td>
<td>0-6</td>
<td>6-21</td>
<td>21-41</td>
</tr>
<tr>
<td>Building type</td>
<td>Full Damage</td>
<td>3-8</td>
<td>8-25</td>
<td>25-28</td>
<td>&gt;41</td>
</tr>
<tr>
<td>Brick in Mud Well Built (BMW)* and Brick in Cement (for 2 buildings)</td>
<td>Total Collapse</td>
<td>0-1</td>
<td>1-5</td>
<td>5-18</td>
<td>&gt;18</td>
</tr>
<tr>
<td>Building type</td>
<td>Partial Damage</td>
<td>0-11</td>
<td>11-31</td>
<td>31-45</td>
<td>&lt;45</td>
</tr>
</tbody>
</table>

Table 5-9 Probability of damage to various types of buildings in Sector A

* : Buildings of brick in Lime construction have been included in this table.
**: Minimum % of buildings experiencing partial damage for adobe buildings is not given in this table

Figure 5-10 Geophysical Survey sites location in Dehradun

Source: Ranjan (2005) and Barua (2005)
Ranjan (2005) calculated Spectral Acceleration (SA) for a site (a school ground – Guru Ram Rai Public School) in the case study ward (Khudbura); at 1 Hz, 5 Hz and 10 Hz frequency at 5 % damping. Based upon the obtained value of spectral acceleration, this site has been placed under zone 3 (having SA ranging from 0.29 g to 0.33 g) and zone 2 (having SA ranging from 0.25 g to 0.29 g). So for 1 Hz frequency at this site SA is 0.08g, and the corresponding figures for 5 Hz and 10 Hz frequency is 0.30g and 0.20g.

Applying the general relation of Trifunac & Brandy (1975) for conversion of Peak Ground Acceleration values to Modified Mercalli Intensity, it is seen that if an intensity of VIII is felt in the study area the following would be the probability of damage pattern to buildings of various wall materials types – this aspect has been depicted in table 5-10. The four columns provide a range (minimum values are in the left most column and the maximum value is in the right most column) of probability of damage pattern to buildings. This table with four probabilities will be later used as a look-up table after having spatially located the buildings based upon their vulnerability (discussed in the following section).

<table>
<thead>
<tr>
<th>Building type</th>
<th>PGA (% g) : 20-35</th>
<th>Damage Probability for each Building</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MMI : VIII</td>
<td>Prob1</td>
</tr>
<tr>
<td>Adobe + Field Stone Masonry Buildings** (22 buildings)</td>
<td>Total Collapse</td>
<td>35</td>
</tr>
<tr>
<td>Brick in Mud (BM) (2 buildings)</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Brick in Mud Well Built (BMW)* and Brick in Cement (131 buildings)</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Adobe+ Field Stone Masonry Buildings** (22 buildings)</td>
<td>Partial Damage</td>
<td>-</td>
</tr>
<tr>
<td>Brick in Mud (BM) (2 buildings)</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Brick in Mud Well Built (BMW)* and Brick in Cement (131 buildings)</td>
<td></td>
<td>31</td>
</tr>
</tbody>
</table>

**Table 5-10 Damage probability for each building wall material type**

*Note: Prob1 indicates minimum probability of total collapse or partial damage and Prob4 indicates maximum probability.*

**Building of brick in lime construction have been included in this table.**

**Minimum % of buildings experiencing partial damage for adobe buildings has not given in this table.**
5.4. Determining Spatial Location of Buildings with probability of Total Collapse and Partial Damage

Till the present step and looking to table 5-10, we are in a position to know the buildings that have a probability of experiencing total collapse and partial damage in case of an earthquake of MMI intensity VIII. However, we are still not a position to know which (and hence the spatial location) are the buildings. This section looks into the same.

For determining spatial location of buildings that have a probability of being totally collapsed or partially damaged, from all the primary data on individual buildings collected (also refer Appendix III); six parameters related to the buildings’ physical condition, were considered for analysis as usually these are the parameters that influencing the behaviour of buildings during an earthquake. These parameters are the number of stories, building detachment, observed cracks, observed condition of walls, shape of the building and slope of the terrain that it is located on. The overall condition of the building mentioned in section 5.1.5 has not been taken into consideration since this is based purely upon the surveyor’s discretion and hence can be considered as a highly subjective judgement.

5.4.1. Recoding and Standardisation of Parameters for Analysis

For the purpose of bringing the various sub types (refer Appendix VII) for details on the sub types, each sub type describes the parameter related to building condition) of each of the above six parameters affecting building vulnerability into ordinal variables and hence three (building cracks, building wall condition and building shape) of the six parameters given in Appendix VII had to be recoded i.e. higher the number for each parameter for individual building; the more the vulnerability of a building in the event of an earthquake. For example, in case of the parameter ‘shape of building’ there are three sub types i.e. square, rectangular and other shapes (such as narrow rectangle, ‘T’ shaped, ‘L’ shaped, etc. For these, the recodes have been given as 1, 2 and 3 respectively; these recodes are in the ordinal scale from low to high level of vulnerability of a building depending upon the shape of the building.

Further in order to standardise the original or recoded values of each parameter for individual buildings, the standardisation had to be done on a 0 to 1 scale. Since building vulnerability can be considered as a ‘cost’, the lower the score that would be obtained for each of the six parameters for an individual building, the more the level of it’s vulnerability.

The standardised scores assigned to each of the above mentioned six parameters were summed up for individual building. The range of the summed up values for the building was from 2.14 to 6.00; these were grouped into four classes (low through very high). The four class groups of the summed up values were visualised as a layer in ArcGIS 9.0 – also refer figure 5-11. Lower the value of summation obtained for each building, higher its chances of being vulnerable to earthquakes and perhaps even collapsing.

Based upon the map depicting the level of risk for each type of building (wall material wise), the location of these buildings and referring to table 5-10 (which is basically a look-up table to indicate the probability level of collapse or partial damage of a building), we can say that a particular building is highly vulnerable (due to it’s physical condition) and has a probability of collapsing of buildings.
The figure 5-11 depicts the vulnerable buildings based upon the above description. It is seen in the table 5-11 that nearly three fourths (72%) of the buildings have low to medium risk of being susceptible to the effects of an earthquake whereas the remaining have high to very risk. The buildings in the very high risk category are 4 and based upon the filed experience of the researcher, these buildings need immediate attention. The 40 other buildings that figure in the high risk category also need attention at some stage.

However, even if a single occupied building collapses or non-structural elements from buildings fall, this is a serious cause of concern and hence the fact that the remaining 15% of the buildings have medium to highest range of risk is to be read as an early warning and a call for necessary steps to be taken for ensuring that the vulnerability of such building reduces by way of structural strengthening, IEC programmes, etc.

Also, depicted within the figure 5-11 are the buildings identified by the community based upon their perception about risky buildings particularly in case of an earthquake. It is seen from the figure 5-11 that there are 24 buildings units that are perceived as risky by the community, however, not all these are depicted in the buildings having high (including those having very high and highest) probability of being totally collapsed or partially damaged. In fact only eight buildings have been included in the

<table>
<thead>
<tr>
<th>Range</th>
<th>Classification</th>
<th># of Buildings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.14-3.00</td>
<td>Very High</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>&gt;3.00 – 4.00</td>
<td>High</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>&gt;4.00 – 5.00</td>
<td>Medium</td>
<td>52</td>
<td>33</td>
</tr>
<tr>
<td>&gt;5.00 – 6.00</td>
<td>Low</td>
<td>63</td>
<td>39</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>159</td>
<td>100</td>
</tr>
</tbody>
</table>

**Table 5-11 Number of Buildings in each Vulnerability Class**

*based upon building survey*
range of buildings having high, very high and highest amount of vulnerability. This establishes the fact that community based approach not only reinforces the GIS based approach but also provides additional information on vulnerable (risky) buildings.

Hence a wider range of buildings are identified with a combination of both these approaches and this information can be useful for inputs in the disaster management plan (for example, targeting of zero downing of the buildings that need to be strengthened in the city by the urban local body etc.). The figure 5-11 gives a combined view of the building vulnerability levels based upon survey, the community perception as well as wall material of the buildings.

5.5. Community Based Risk and Resource Mapping

The figure 5-12 above provides the view of identified buildings by the community (local residents) of Sector A that appear to be ‘risky’ or likely to collapse in the event of an earthquake striking the area. Twenty four buildings have been identified, these constitute 15 % of the total number of buildings in Sector A. These buildings house 41 families, 9 shops and 7 other units such as Schools, Offices, Home based Enterprise (weaving), etc. A 1.8 Million Litre per Day (MLD) capacity Elevated Surface Reservoir is also included in the count of other buildings.

As the maximum and minimum damage states probability figures for a specialised structure such as an ESR are not available in the damage with reference to a given intensity of earthquake matrices, the probability of damage with reference to a given intensity of earthquake to this ESR is not known. However, during the risk and resource mapping exercise, the local community who resides in the vicinity of the ESR had severely complained of the fear and a kind of chronic ‘psychological stress’
that they face with the presence of the ESR (as well as electricity transformer next to it). The residents that stay very near to the ESR see it as a threat not only to them, but their concern is particularly for the children that study in the City Board School due to it being located right in the school compound. Interestingly, even in the HAZUS casualty loss estimation module, aspects such as the psychological impact of population in the pre disaster scenario have not yet been able to be captured and in this respect the community based approach fares better than a pure data oriented technocratic approach (such as HAZUS).

5.6. Comparison of Results (GIS based as well as Community based)

Based upon the results depicted in section 5.3 and 5.4, it is seen that there exists almost a two fold difference between the GIS based identification of risky buildings (total 44 in all – considering the buildings in the high and very high risk categories) and the buildings that have been identified by the community (24 buildings). This is due to a variety of reasons some of which are: the selection of parameters (and sub types in the ordinal scale) that affect a building condition, the weighing and summation method used; the perception of the community of risky buildings can be biased at times since it is purely on their perception (as in the case of the ESR which being a specialised structure would be having structural which did not fall in the high risk categories as per the physical survey results) and also be based with a slight bias (this is also observed during the relief distribution when the leaders or community, members to whom it reaches to for distribution within their community - the leaders often tend to store more than the required quota for their use.)

In the present risk and resource mapping exercise, some of the community representatives were present and this phenomenon could also lead to increase in the number of buildings that are perceived as risky by the community. One reason for this is that, a typical question that is usually asked to the surveyor by the community during socio-economic surveys is whether there will be any benefit (in terms of resource allocation, etc.) to the respondents and in this particular case people from the community may have marked their house as risky with the expectation that their houses may be prioritised during any sort of programme for as an intervention in order to improve/strengthen the houses of the residents structurally.

None the less, it is important to recognise the fact that the community is able to give a clear output of what was asked from them (in this case listing out the risky buildings in the surroundings of their residences) and also have a good idea of their surroundings, is able to locate their houses on the map (which is also indicative of the viability of the use of GIS based outputs such as maps at the grass root level) and can contribute to the results that a GIS based analysis brings out. This type of community based mapping exercise is also a way to get the community involved at a wider base (as compared to just the Sector Wardens, the Post Wardens and the people whom they train) with women, children as well as men participating in the exercise.

The outputs of the GIS based analysis as well as the community based approach mentioned above leads to obtaining a wider array of results which will be beneficial to the Urban Local Body (ULB) when it comes to actually zeroing down of buildings that need to be identified for provision of attention (for example - seismic strengthening). Thus, community are a good source of inputs on their
vulnerabilities and can provide ‘value added’ information and at the same time reinforce the results obtained from technocratic (for example GIS) based analysis.

5.7. Summary

This chapter described the process of identifying buildings that have a probability of being susceptible to total collapse and partial damage according to the building survey conducted during the study. Based upon the damage matrices adapted by NSET, Nepal the number of buildings (according to material of wall) that have a probability of total collapse and partial damage were determined. After this, in order to know the actual spatial location of the identified number of buildings, the buildings in Sector A were classified (from low through very high level of risk) based upon the six most important physical characteristics that have an influence on the building behaviour in case of an earthquake occurring in the area. Also, the buildings were depicted according to their wall material. Furthermore, the community input based upon their perception of risky buildings was also depicted for the same area (Sector A). Visualisation by overlaying of these three layers provides indication of the buildings that have a probability of being affected in case of an earthquake and also narrowing down on specific buildings that would need immediate attention by the ULB within or outside the framework of the DMP for the city. This input - in terms of the identified buildings - will be used for the population vulnerability assessment in chapter 8.
6. Population Distribution

6.1. Introduction

This chapter deals with the core aspect of the study i.e. the population vulnerability for the study area. The presence of people in the case study ward is available based upon the 2001 Census figures (8901 persons). These are essentially the aggregated figures at ward level. As these figures pertain to data that is already four years old (as of 2005) during which time there is a high possibility of many residents having moved in or out of the study ward; hence; the census figures do not really give a true representation of people that are currently (at the time of the field survey conducted in October 2004) living in the ward. Thus, in the ensuing analysis these figures have not been utilised for attaining population distribution in the study area. On the other hand; there being available a highly updated analogue data base in terms of population demographics on a house to house basis (from the Civil Defence Organisation’s sector wise register); this source of information has been utilised for determining the population distribution and vulnerability for one sector (A) in order to depict how this exercise can be done.

Population presence and distribution for sector A has been depicted in the first section of this chapter so as to have continuum from the previous chapter (which focuses on the building vulnerability aspect for the same sector). Part of the results on population distribution will feed into the population vulnerability (described in the next chapter) in terms of derive the number and extent of casualties based upon building damage/collapse. Thus, major thrust of the present chapter is on the aspect of establishing the distribution of population across an area and estimation of casualties (also refer Appendix VIII).

6.2. Population Presence

As discussed in section 4.1.4 the population figures pertaining to people living in one sector of the study (Sector A) as per the Civil Defence Organisations register there are 1193 persons and hence as in the case of the Census data on population, this essentially implies to the night time population present in the area. These figures do not include the people working/studying/visiting in non-residential occupancy class buildings such as commercial, industrial, institutional, etc. for time durations spanning over several hours of a day as well as those who can be considered as part of the ‘floating’ population. Such floating population has been mainly grouped for the purpose of the present study into two categories i.e. a) those who come and go in and around the buildings (and on roads of the study area and; b) those who are present at a particular location/building for a duration of less than an hour or at times only for a part thereof (for example people on/in vehicles). Although the exercise of mapping population distribution and also linking the vulnerability of buildings to that of population can be done highly comprehensively, the present chapter attempts to do the same in such a way that the process can be replicable to other sectors and in turn to other wards in the city with certain inputs from stakeholders such as the ULBs, CBOs – this aspect has been discussed in detail subsequently in the next chapter.
Population presence in a given environment (both indoors as well as outdoors i.e., within buildings or on roads, streets, etc.) determines the extent of vulnerability of people i.e. the more vulnerable the buildings are - the more vulnerable are the people. This is also the basic premise of the HAZUS methodology which is also based on the assumption that there is a strong correlation between building damage and the number and severity of casualties. It is often said in case of natural disasters such as earthquakes that it is not the earthquake that injures people or leads to fatalities but it is the buildings that cause harm to people based upon their behaviour during an earthquake. Besides this, population vulnerability is also determined by the demographic characteristics of the people such as age, disability if any, occupation, etc.

People’s activities are determined by their propensity to engage in the activities as well as the opportunities to engage in activities. Opportunities of people to engage in activities is determined by perceived availability and quality of the service or facility whereas; the propensity to engage in discretionary (secondary) activities is a function of the preconditioning factors as well as the predisposing factors. The preconditioning factors are related to the basic demographic characteristics of people and this very aspect needs to be studied in order to know their activity patterns and derive the actual presence of people within the buildings (in the present chapter - for the buildings within sector A). The presence of people within buildings can be for their primary activities (such as cooking, eating, bathing, sleeping, etc.) – in case of residential buildings and for secondary activities (such as studying, working, visiting, shopping, etc.) in case of buildings with non-residential use and for both primary as well as secondary activities for buildings with mixed occupancy class.

6.2.1. Population Presence in Buildings

Section 4.1.2 discussed about the canvassing of survey schedules in order to determine the activity pattern/details of people. For determining their presence within buildings, details of the activities – particularly secondary activities (in terms of the time and location of such activities) of people living, studying and working within the case study ward were obtained by survey of people in their residences/enterprises/schools (also refer Appendix IV to see the survey schedule). As mentioned earlier, 6% samples of buildings were taken in the entire ward and since a detailed analysis of Sector A was to be carried out and this being the first sector from which the survey began; a larger sample size (13%) of households/enterprise was collected from this sector. The distribution/location of the sampled households/buildings has been depicted in figure 4-6 in chapter 3. Details of samples have been selected for activity pattern surveys presented in the table 6-1 hereafter.
The broad statistics of the samples for activity pattern surveys has been depicted hereafter in table 6-

<table>
<thead>
<tr>
<th>#</th>
<th>Specific Building Occupancy</th>
<th>Total Number of Buildings in the ward</th>
<th>Number of Buildings Surveyed</th>
<th>Sampled HHs/Enterprise in building</th>
<th>Occupation/Status of Primary Respondent</th>
<th>Average Number of people in the HH/Enterprise/School in each Occupancy Class</th>
<th>Floating population in the Building HH/Enterprise/School during the 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Residential</td>
<td>794</td>
<td>44</td>
<td>60</td>
<td>Housewife, Children, Working Person, Old Age/Retired Persons</td>
<td>5.49</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Commercial (Shop)</td>
<td>24</td>
<td>1</td>
<td>1</td>
<td>Shopkeeper, Helper, Employee</td>
<td>1.4</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Other Units (Residential + Commercial, Office, Dairy, Whole sale Shop)</td>
<td>195*</td>
<td>18</td>
<td>18</td>
<td>Owner, Employee, Customer</td>
<td>6</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>School</td>
<td>15</td>
<td>2 (11 Buildings)</td>
<td>2</td>
<td>Principal, Teachers, Helpers, Watchman</td>
<td>290</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1028</td>
<td>30</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* There are two structures beside the water body and these have been considered with the figures on ‘other units’

Table 6-1 Details of Sampled Households/Enterprise

### 6.2.1.1. Population Presence in Buildings

Although the sample survey data provided a huge scope of analysis such as determining the travel destinations of people as part of their discretionary activities such as travel to work, shopping, etc. and other details particularly those that are very useful in the subject of transportation; since the present study focussed particularly on the population vulnerability as a consequence of the vulnerability of buildings within the study area, the aspect of people’s presence within the buildings of the ward (especially where they spend a lot of their time), was fundamental to the present analysis.

Based upon the sample survey data of one hour resolution of peoples presence within buildings (from data of activity pattern survey) in the ward; the average % of people for each occupancy class was determined. Although during the canvassing of the questionnaire the respondents were able to give a relatively detailed account of presence in their house/enterprise/school by giving the approximate presence of each member of house/enterprise/school (by narrating the discretionary activities and at times explaining the whole daily schedule of household/enterprise members). However, while accounting (rather mentioning) about the approximate number of people visiting the house/building for durations shorter than one hour, referred to in the present study as ‘floating’ population (for example vendors, sales-persons, house-help, customers, visiting parents/guardians to schools) the
estimates seemed to be very rough with the respondents (such as shopkeepers) giving highly approximate numbers of customers that came to the shop in a day (refer table 6-1).

6.2.1.2. Population Presence in House

Having obtained the data on peoples activity details and schedules; the data on hourly presence of each person was noted and the total number of people in a given house were summed up for each hour. Thus in this way, the number of people that were actually present during each hour on each type of the day (and night) was obtained for every household surveyed. The presence of people (in terms of %) in the household was thereafter determined (by dividing the total number of people present in the house during each hour of the day with the total household size). By taking the average % presence of people in all the households surveyed (considering an average household size of 5.49) during the entire 24 hours for three different types of days viz. a weekday, a Sunday and a holiday, a trend as depicted in figure 6-1 and table 6-2 was obtained. The figure 6-1 reveals that there is variation in the presence of people during different hours of the day and also this is dependent upon the type of day.

Figure 6-1: Average % of household members in house at every hour different days

| Day   | 04 to 05 | 05 to 06 | 06 to 07 | 07 to 08 | 08 to 09 | 09 to 10 | 10 to 11 | 11 to 12 | 12 to 13 | 13 to 14 | 14 to 15 | 15 to 16 | 16 to 17 | 17 to 18 | 18 to 19 | 19 to 20 | 20 to 21 | 21 to 22 | 22 to 23 | 23 to 24 | Midnight to 01 | 01 to 02 | 02 to 03 | 03 to 04 |
|-------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------------|----------|----------|----------|
| Week  | 98       | 98       | 94       | 91       | 81       | 70       | 65       | 56       | 46       | 39       | 33       | 31       | 28       | 22       | 16       | 10       | 7         | 5         | 3         | 2         | 1         | 0         | 0         | 0         | 0         |
| Sun   | 98       | 98       | 94       | 91       | 87       | 75       | 68       | 64       | 60       | 58       | 56       | 54       | 50       | 44       | 39       | 34       | 31       | 29       | 27       | 25       | 23       | 21       | 19       | 17       |
| Holiday| 98       | 98       | 94       | 91       | 84       | 79       | 75       | 71       | 67       | 63       | 59       | 56       | 54       | 51       | 48       | 45       | 42       | 39       | 36       | 33       | 30       | 28       | 25       | 23       |

Table 6-2: Average % of People Present in a residence on different days of the year
It is observed from the above figure 6-1 and table 6-2 that there is never cent % presence of people in the households surveyed on any type of day. The trends of peoples presence on all types of days is more or less of the same pattern. Close observation reveals that on all three types of days, less number of people are present during two time periods (07.00 to 14.00 hours) and 17.00 to 19.00 hours. In fact, the least presence of members on any type of day is during the morning hours.

However, one thing to note is the relative similarity of peoples presence on a Sunday and Holiday. This is due to the fact that during canvassing of the questionnaire (spanning on an average about 40 minutes for each household); the respondents did not give specific replies about their activities on a holiday, probably in many cases - due to having lost their patience in answering to questions that are remotely as well as and indirectly understood as related to ‘privacy’ and ‘security’. Another reason was that of difficulty people faced in recalling a set routine on a holiday (since as such people responded as there being no set routine of their activities on a holiday and that their routines vary greatly with the type of holiday. For example, on the Independence day (15th August), children go to school for a few hours for hoisting the national flag and participating in cultural programmes whereas, most government as well as private sector offices are closed, on the day of the Holi festival, people (mainly children and youth) go out (to play with colours) with their friends and relatives. Thus, there is enormous variability in peoples activities during holidays and hence this data has not been adequately captured in the present study. There is a need for determining appropriate data capturing mechanism for people’s activities on Holidays.

### 6.2.1.3. Population Presence in House in Time Slabs

| Day          | 04 to 05 | 05 to 06 | 06 to 07 | 07 to 08 | 08 to 09 | 09 to 10 | 10 to 11 | 11 to 12 | 12 to 13 | 13 to 14 | 14 to 15 | 15 to 16 | 16 to 17 | 17 to 18 | 18 to 19 | 19 to 20 | 20 to 21 | 21 to 22 | 22 to 23 | 23 to 24 | Mid night to 01 | 01 to 02 | 02 to 03 | 03 to 04 |
|--------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|----------|----------|----------|
| Week day     |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |           |          |          |          |
| N            | 98       | 83       | 37       |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          | 98        | 98       |          |          |
| Early Morning|          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |           |          |          |          |
| Morning to Early Afternoon |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |           |          |          |          |
| After noon to Early Evening |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |           |          |          |          |
| Evening      |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |           |          |          |          |
| Night (N)    |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |          |           |          |          |          |

Table 6-3: Population presence in house time slab wise

Based upon the details of peoples presence in the house on a week day (presented in table 6-1) and; for the purpose of simplification of interpretation and future usability (discussed in the next chapter) of such analysis the entire 24 hours has been discussed in detail hereafter. A weekday has been selected as this is the most commonly occurring type of day, also, responses to the weekday activity patterns of people were more clearer as compared to other days. The figures of average % presence of people on a week day as given in table 6-1 were averaged and grouped into 5 time slabs viz. Night (N), Early Morning, Morning to Early Afternoon, After noon to Early Evening and Evening. It is observed that the least risky period (for household members) exists from 08 to 13 hours i.e. the entire morning to early after noon. This is the time when the least number of household members are present (2.1 persons or say approximately 2.0 persons) in the house. Household activity pattern data revealed that such members of the household are usually the non working and non studying members (for
example, housewife, infant/s and aged person/s). The highest % of households members (97.9 or say 98 %) is seen between 23.00 to 04.00 hours. The reason for this 2.1 % absence or the non cent-per-
cent presence of the household members during these hours (almost midnight to the wee hours) is due
to the fact that in 4 of the sampled households (to whom the activity pattern questionnaire was
canvassed), there were people (male members) that did not reside in the building with their families
on a day-to-day basis due to having work (such as a job at Hydel Power Generation Station about 100
kms from Dehradun, with the Railways in another place outside the city, etc.) and visited their
families as they had employment on Sundays or for a couple of 10 days (e.g.10 days in a row). Thus,
in the analysis, the presence of these members has to be considered not as an entire cent % presence
but a fraction thereof – for example, if a household member stayed with his/her family for 10 days a
month and the rest of the two thirds of the month he was at work outside the city, then his/her
presence was entered as 0.33 (equivalent to 33 % presence) instead of 1 (equivalent to 100 %
presence) in the data on presence of household members for 24 hours.

The presence of people during the after noon to early evening is moderately risky (average % of
presence of household members is 68 %) when the children of the households either go to private
tuitions or play outside their houses (usually on the streets) or when people go to buy groceries or
simply go and visit their neighbours/relatives both within and outside the ward.

The presence of people in the evening from 20.00 to 23.00 hours is not to the maximum extent and is
98% since not all the members of the households are present. The people who are not usually present
in the house during these times are those who come back from work (especially those having their
own businesses or working in a private enterprise return home after the shops in the
market/commercial areas close down (around 20.00 hours in the city) and also the usual time of
dinner time of people being after 20.00 hours.

6.2.1.4. Population Presence in House

Presence of population in other types of units surveyed (i.e. Shops, Other units - such as Residential +
Commercial, Office, Dairy, Whole sale shop) and Schools has been depicted in the Appendix X.
Besides, for the sake of connectivity with the previous sub section, the average % presence of people
in a house has been given on the first row along with the average household size. It is seen from the
Appendix X that an entirely different trend is seen for non residential building occupancy classes.
While the average household size is based upon the Civil Defence register figures for Sector A, the
average size of shops, other units and school is based upon the sample survey results.

Finally, GIS based analysis (discussed in the next section) has been carried out for obtaining the total
population figures for each hour (also the % of the actual residential population of 1208 persons –
according to the Civil Defence Register for the month of October during which the survey was
conducted) has been given in the Appendix X.
6.2.1.5. Floating Population

Apart from people being present in buildings (by living/working/studying) per-se; there are also people who come (for shopping, visiting people/religious places/school, etc. for few minutes) from outside and stay for a while in/near the buildings in Sector A and then leave. In case of 80% of the sampled households/enterprise/school the duration of such activity was less than an hour. As for example; an adult may visit the school to leave his/her child/ward; or; a person may go to a shop to buy some groceries and then leave within a few minutes. In case of shops such as a video games shop (one of the sampled shops during the filed survey a child may visit a video games shop and leave before an actual hour has elapsed. In order to capture such peoples (mostly non-residents, non-workers and school children) presence in or just outside buildings for short durations; the questionnaire canvassed had a section on how many guests/customers come to the house/shop, etc. (also refer Appendix IV). In all the sampled households/enterprise/school, there was no accurate answer. The possibility for inaccurate answers are also likely as there were no building occupancies in the case study area in which the entry of a person/vehicle is noted (for e.g. in Government organisations such as the Secretariat, etc.) and also almost all the respondents pointed out that their estimates were ‘rough’. As such the estimate of the floating population was a gross figure for the number of people for an entire day for each of the four occupancy classes (presented in table 6-1). Also, since the presence of the floating population is not known on temporal basis; these figures have not been depicted in temporal maps of population in the buildings and distribution within Sector A. Nonetheless, the total floating population in an area can be calculated in the following way:

\[
\text{Total Floating Population in the area (Sector A)} = \sum_{i=1}^{n} \left( \text{Number of Households} \times \text{Average Number of Floating Population} \right) + \sum_{i=1}^{n} \left( \text{Number of Other Units} \times \text{Average Number of Floating Population} \right) + \sum_{i=1}^{n} \left( \text{Number of Schools} \times \text{Average Number of Floating Population} \right)
\]

6.3. Population Distribution

For determining the hourly presence of people in buildings across space (i.e. Sector A) the ideal formula suggested is:

\[
\text{Hourly Presence of People for each building} = \sum_{i=1}^{n} \left( \text{Number of Households} \times \text{Average Number of Persons} \right) + \sum_{i=1}^{n} \left( \text{Number of Households} \times \text{Average Number of Floating Population} \right) + \sum_{i=1}^{n} \left( \text{Number of Shops} \times \text{Average Number of Persons} \right)
\]
POPULATION VULNERABILITY FOR EARTHQUAKE LOSS ESTIMATION USING COMMUNITY BASED APPROACH WITH GIS

\[
\sum_{i=1}^{n} \left\{ \text{[Number of Other Units]} \times \text{(Average Number of Floating Population)} \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Other Units]} \times \text{(Average Number of Persons)} \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Other Units]} \times \text{(Average Number of Floating Population)} \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Schools]} \times \text{(Average Number of Persons)} \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Schools]} \times \text{(Average Number of Floating Population)} \right\} \quad \cdots \cdots \cdots \quad (a)
\]

However, as discussed in the previous section; we do not have information on the temporal
distribution of the floating population and hence the floating population has been taken into account
while calculating the hourly population distribution of people in Sector A.

Thus, the presence of people on an hourly basis has been calculated by the following formula in GIS
environment (ARC GIS 9.0) based upon the above information pertaining to households, shops,
school and other units.

**Presence of People in the Building**

\[
\sum_{i=1}^{n} \left\{ \text{[Number of Families residing in each building]} \times 2.3 \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Shop in each building]} \times 2.0 \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Schools]} \times 90 \right\} + \\
\sum_{i=1}^{n} \left\{ \text{[Number of Other units]} \times 2.8 \right\} \quad \cdots \cdots \cdots \quad (b)
\]

In the above formula, it is to be noted that the numbers depict the average number of people present
during a particular time period, for example between 09 to 10 hours.

In the above formula \((b)\), the presence of number of persons in schools (also refer Appendix IX) was
considerably high and in terms of the actual buildings (footprints) within each school compound the
number was greater than one (for example, 4 in case of the City Board School), thus; the number of
persons per school building was divided by the number of buildings (in the school compound). Also,
since the study dealt with population vulnerability, the presence of animals was not been included in
the above equation although the processed data set does allow for calculation of non-human (animal)
presence within the buildings. In fact, presence of animals is an important aspect and in case of the
particular case study ward, as there are many dairies, the vulnerability of animals also needs to be
looked into. From this it can be said that aspects such as animal vulnerability is highly dependent
upon the intrinsic characteristics of an area and the types of land use and building/structure
occupancies.
The figure 6-3 depicted hereafter provides an overview of the presence of people in each type of building occupancy for four time periods selected for (four of the five time groups discussed earlier in section 6.2.1.2). The figures of peoples presence in various occupancies mentioned in the above formula (b) have been given in table 6-4. Also, the presence of people (in % terms) with respect to the total residential population in Sector A has also been given. It is seen that there is no population (as depicted conspicuously by the absence of any circle on the building footprint) in a few buildings in the upper left map pertaining to one of the ‘night hours’ (e.g. 02:00-03:00 hours). This is due to the fact that some of these are either uninhabited (with building being vacant or abandoned – since they are in poor condition or belong to the Jhande Saheb’s Trust) or due to being used for institutional use such as school, etc. Thus, although these appear in a way as one of the safest buildings (in terms of having less risk to humans who are not within these buildings) but in reality this is not true since there are people within adjoining (semi detached to these buildings) as well as on roads who may be affected by these buildings.

| Week | 04 to 05 | 05 to 06 | 06 to 07 | 07 to 08 | 08 to 09 | 09 to 10 | 10 to 11 | 11 to 12 | 12 to 13 | 13 to 14 | 14 to 15 | 15 to 16 | 16 to 17 | 17 to 18 | 18 to 19 | 19 to 20 | 20 to 21 | 21 to 22 | 22 to 23 | 23 to 24 | 24 to 01 | 01 to 02 | 02 to 03 | 03 to 04 |
|------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| A    | 1204.5   | 1224     | 1175     | 1088     | 762      | 1285     | 1188     | 1229     | 1175     | 101.0    | 1134.9   | 910.75   | 905.95   | 964.21   | 1102     | 1087     | 1123.9   | 1188.9   | 1188.9   | 1188.9   | 1188.9   | 1188.9   | 1188.9   |
| B    | 99.7     | 93.1     | 97.3     | 90.1     | 63.1     | 106.0    | 98.1     | 102.0    | 93.9     | 92.9     | 78.9     | 75.4     | 74.9     | 79.6     | 91.2     | 90.0     | 93.0     | 98.4     | 98.4     | 98.4     | 98.4     | 98.4     |
| C    | 89       | 4.5      | 102      | 57       | 97       |

Table 6-4 Presence of people in various occupancy classes
A : Total Population present in all building occupancy classes according to survey data
B : % of total recorded residential population as per Civil Defense Register (for Sector A it is 1208 persons)
C : Average % of population present with respect to total residential population
* : There is an orphanage in the Sector A, this has not been taken into account in other buildings and hence there is a difference of 19 people.
# : Total recorded population

In the table 6-4 (also refer figure 6-2), the presence of people at different hours for all building occupancies on a week day has been given. From the table, it is seen that there is a fluctuating trend of peoples presence in these occupancy classes. While comparing to the actual residential population (usually the residential population is concerned in population vulnerability assessment exercises and as discussed earlier, this is not the actual population during the day) data based upon the Civil Defence organisation’s register (there are 1208 persons); it is seen that there is even more than 100 % (of residential population) presence. Infact, as in the case of the people in a single occupancy class - house, the average % presence of people presented in the first row of the above table (6-4) were averaged and grouped into 5 time slabs viz. Night (N), Early Morning, Morning to Late Afternoon, Late Afternoon to Early Evening and Evening. The major contributor to the population figures exceeding the residential population during the Morning to Late Afternoon period could be due to the presence of children (many of whom live outside the ward) in schools and also the children’s parents/guardians come to pick up the children. Another factor could be the return of people during lunch time to their homes during this period.
6.4. Variations in Population Activity Patterns

Box 1: Variations in Activity Profile of Household in Sector A

In order to get a better idea about household activity patterns and the amounts of variability that exists and have not been captured in the present table a households variations in terms of activity patterns of its members has been described hereafter:

One respondent who is a housewife aged 57 lives with her husband, two sons, her daughter in law and a grandson aged 5. The respondent on every tuesday from 15 to 18 hours (4 times a month) goes to religious place (for hymn singing) located at Cannaught Place in the city. Once a month i.e. from 11-2 pm every first Saturday of the month, she visits the market to purchase household groceries.

Her husband although having an insurance agency (and thus is required to visit clients especially in the morning hours) at times stays indoors in the house during 11 to 12 hours due to not having any fixed office type schedule.

The elder son has a milk shop and is thus required to start very early in the morning (at 5.00 hours). The daughter in law is a teacher at the Doon Blossom School in Dalanwala area and has summer vacations (15 days in the winter (December 25 to January 15) and 2 months in the summer (May to June). She visits her mothers house (in Dehradun but in another ward) for 10 days (the dates are not fixed) a year and hence has a different amount of presence in the house in the case study ward. The grandson has holidays on Saturdays.
Figure 6-3 Population Distribution at various hours in different building occupancies of Sector A
The above mentioned account in Box 1 of variations of activities for one household reveals the complexity of attempting to capture people’s activity pattern. There are also variations in peoples presence during festivals both within and outside buildings – especially during occasions such as Jagrans held at various times of the year. In a Jagran, people stay awake the whole night singing hymns - in the case study ward 5 of these take place in each of which the number of people who gather ranges from 200 to 500. The venue of such occasions is right on the street often very close to buildings that are in poor condition. In order to facilitate the usage of space and non–thoroughfare, some of these streets are blocked. The figure depicts one Jagran – the Vishal Jagran conducted on Saturday next to the Durga Mata Temple and extends along the road (through about 50 meters road length) right upto the cross roads near which is a building in a highly dilapidated condition.

Figure 6-4 Jagran in the case study ward (Sector B); dilapidated building right next to the location of this occasion

Population presence in a household is a function of not only the characteristics of a persons with respect to their occupation but can also be that of the religion or ethnic community that a persons belongs to. For example, many Sikh families visit the Gurudwara regularly in the morning and in case of many in the evening for about an hour. Besides the Sikhs congregate at a Gurudwara during all the various birthdays of the 12 Guru’s that they have. Thus, in Sikh society the Gurudwara plays an important destination for many on a daily basis. Similarly, for Islamic men, the Mosque is also an important place of worship and many go there at many (five in most cases) times of the day. In the case study ward there are five temples and one mosque. The Gurudwara at the Jhande Saheb’s Darbar is located just outside the ward boundary opposite to the water tank. Besides, religious trees (such the two trees in the case study ward - Peepal, Banyan) play a crucial place of worship (with temples often being built under them) and the morning (around 6.30 hours and evening around 18.00 am hours the people are present for worship for atleast a few minutes. These are basic examples of the variations that are seen in terms of religious diversity that has an affect of peoples activities.

It is to be noted that the above is in a way a conservative calculation of population distribution; since an area has people present and leaving the area constantly; particularly the people who are on vehicles and pedestrians that are passing through the area, the mobile and stationery vendors and hawkers as well as people just standing on the road shoulders (as there are no pavements). In order to know broad estimates of people on the road and particularly the people who are on/in vehicles and the pedestrians including hawkers; the approximate people/hawkers standing or present at a junction was noted.

6.4.1.1. Profile of Population Groups
The above section showed the presence of people in the buildings located in Sector A. Two groups of population viz. housewives and school children are more vulnerable as compared to other groups (such as people going to work in a shops, offices, etc). The trends pertaining to the presence in the
house of these two groups has been discussed in this section as for the present study we were interested to know about population vulnerability (which is mainly a consequence of vulnerability of buildings and the majority of the buildings in the sector A are residential in which housewives and children are present for longer durations as compared to other of population groups). The details of these two groups in terms of their presence in the house has been discussed hereafter.

**Housewives**

Based upon the activity pattern surveys, the data of housewives (whose age ranged from 81 to 32 years – the average age was 49 years) revealed the following trend (figure 6-5) of average presence of housewives on a weekday, Sunday and holiday in the house. In terms of education levels of the housewives, the lowest education was that of the 82 year old lady who had studied upto class 2. On an average education level of housewives was class 11. However, this education level may not be the correct one since many times people do not wish to reveal their real (often lower than what is stated during replies to questionnaire surveys) educational qualification. The data also reveals that the women with higher level of education go to work.

Looking to the figure 6-5, it is seen that the presence of housewives is cent % from 21.00 hours till 08:00 hours in the morning. In between, during the day, between 08:00 to 11:00 hours, 9 % of the housewives are away from the house and are engaged in activities such as dropping children to school, shopping, etc. Absence of housewives from home on an average is the most during the period 18.00 to 19:00 hours with 33 % of the housewives being away from home.

![Figure 6-5: Average presence of Housewives in house on a weekday](image)

**School Going Children**

Based upon the activity pattern surveys, the data of school going children ranging from 4 to 17 years age (average age was about 9 years) revealed the following trend (figure 6-6) of average presence of school children on a weekday, Sunday and holiday in the house.

![Figure 6-6: Average presence of School Going Children in house on a weekday](image)
On the whole, presence of school children is cent % from 19:00 hours till 07:00 hours in the morning. In between, during the day, from 09:00 to 11:00 hours the children are away from home including those in the Kinder Garden. Children return back home by 14:00 hours after school closure and their absence from home is again visible at 16.00 hours with 66 % of children being out of their houses to play, go for private tuitions, etc.

Detailed computation and explanation regarding the peoples presence outside buildings (i.e. on road) junctions and segments has been discussed hereafter.

### 6.4.2. Population Presence on Road Network

Roads constitute about 15 to 20 % of any area as per the UDPFI norms in India. In case of the study area, roads are used by people for a variety of purposes. In the study area as in the case of many other countries, the shoulders of the roads as well as the carriage width is used not only by vehicles moving on the road, but also by pedestrians, hawkers (stationary as well as mobile) as well as by animals (such as dogs, buffaloes & cows that are mostly accompanied with herds men, etc.). Also, the road at times serves as a land use and as an added extension of an enterprise and even sometimes a house.

For determining the population presence on roads, the road network needs to be analysed not only in terms of the geometric configuration but also in terms of the movement of vehicles and people in various directions along the road network. The traffic and pedestrian volume counts for the present study were carried out only from the morning to evening and not at late night hours till the wee hours of the morning. The mapping of the road network with respect to the above described population presence diurnally has been discussed hereafter for one time period (one hour – between 09:00 hours and 10:00 hours) as an illustration of the number of people present/moving by junctions (of Sector A) during an a week day.
6.4.3. Computation of Persons on Roads based upon Traffic Volume Counts

The example again of sector A has been taken in this section for discussing about people’s presence and distribution on roads and, traffic data for four major entry points (junctions) to this sector around the time period 09. to 10.00 hours has been analyzed. This time period has been chosen for being able to later compare the results with peoples presence within buildings.

The shape file was converting the coverage and cleaned building to obtain a geometric network. Also refer Appendix XI for detailed process diagram. The traffic count data at each junction (counted direction wise during the traffic survey) was converted into persons per minute based upon the assumed vehicle occupancy rates presented in table 6-5.

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Cars</th>
<th>Taxis</th>
<th>Tempos</th>
<th>Autos</th>
<th>Bicycle</th>
<th>Scooters</th>
<th>Motorcycles</th>
<th>Big Lorry’s / Tractors</th>
<th>Vendors Lorries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy Rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Assumed)</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>1.5</td>
<td>1</td>
<td>1.5</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: Based upon field observations, RITES (2004) and JICA (1999)

Table 6-5: Vehicle Occupancy Rates

The traffic volumes counts and counts of pedestrians at junctions was taken and pertain to different time periods for different junctions as mentioned in the earlier chapter 4. Based upon the traffic counts of junctions for various times of the day – the figure 6-7 below depicts the number of persons that were present at the junctions even for a few seconds (since most of the people are on vehicles) during the entire 60 minutes between 08.30 and 11.15 hours. Having converted the number of vehicles into equivalent persons based upon occupancy rates mentioned in table 6.5 the total persons comes to 9996 persons (8826 persons in/on vehicles and 1170 persons walking) who either travelled on/in a vehicle or walked by (considering both pedestrians as well as hawkers) the junction and hence were in the vicinity of buildings in Sector A.

![Figure 6-7: Junctions surveyed (left) with traffic data (right)](image-url)
However, the above method of indicating the number of people present on the junctions is inappropriate and in fact the population on the roads needs to be distributed along the road network.

In order to determine the population distribution along segments or links the traffic count data for the same five junctions depicted in figure 6-8 and 6-9 was used for further analysis and the process has been discussed hereafter.

The direction-wise number of vehicles and vendors at each junction was converted into persons per minute (since the data for four of the five junctions pertained to different times of the morning (ranging from 08.30 to 11.15 hours – refer figure 6-7). The direction-wise persons per minute value was averaged in case of both ‘To-From’ as well as ‘From-To’ directions in order to obtain a value that is an average figure representing the persons_vehicles per minute. It is to be noted that such averaging was only done for junctions with traffic and pedestrian volume counts of two non-similar timings. The direction-wise persons_vehicles per minute was converted into hourly values by multiplying by 60. Similarly, hourly pedestrian volume was also calculated. The per minute vehicles (in terms of persons and hereafter referred to as ‘persons_vehicles’) and pedestrian figures were depicted on a junction diagram (with arrows depicting direction-wise people in/on vehicles and pedestrians) (the hawkers and vendors have been included along with the pedestrians). Based upon the junction diagram ‘To-From’ and ‘From-To’ persons_vehicles and pedestrians was assigned for each road segment (in the attribute table of ‘section’ of the geometric network.

Thereafter, average speed was assigned for the road for vehicles and pedestrians considering the secondary data available on speed from RITES (2004) – also refer figure 6-8, road width and condition and field observation. As seen in the figure 6-8, the Tilak Road which is a major arterial road and passes from the eastern edge of the ward has an average traffic speed of less than 5 km/hour. Considering this figure and the road surface, width and surrounding landuses in sector A, the road segments were assigned speeds ranging from 5 km/hour to 3.5 km/hour. The average speed of pedestrians (people walking and vendors) was assumed as 2 km/hour.

The next step involved calculating the travel time in minutes for which the following formula was used:

\[
\text{Travel Time} = \frac{\text{Length}}{\text{Speed}} \text{ (meter/meter per minute)}
\]

Where, Speed in Km/hour = \[\frac{1000\text{m}}{60 \text{ minutes}}\] = 16.67 m/minute

Thus from the above formula Travel Time required for vehicles and pedestrians to move along each segment was obtained in m/minute.

Thereafter for calculating the total people present (in/on vehicles and pedestrians) on each road segment per minute (i.e. Total_Persons_Vehicles and Total_Persons_Pedestrians or say ‘Y’); the total time (say ‘X’) it takes to travel along the road segment was divided by 60 minutes (i.e. for an hours duration) and this result was further multiplied by total persons (in/on vehicles and pedestrians) that were along the segment for one hour (this was obtained from the absolute number of vehicle_persons and pedestrians that passed from one junction to another junction along different road segments during an hour for example; in between junction and B and B5 the value of ‘Y’ was 3635 persons).
It is to be noted that in the present analysis for calculation of total travel ‘X’, it is assumed that the people travel from one junction to another and do not get off the road at any intermediate place (this may not be true in reality particularly for pedestrians who may go to adjoining shops, houses, etc.). Thus, in the case of the road segments between junction B and B5, there are four segments and the travel time ‘X’ taken for vehicles (at 5 km/hour in case of vehicles and 3 m/hour in case of pedestrians). The following formula was applied using field calculator in attribute table of section (Also, refer to appendix XII for the table on section with attribute details).

\[
\text{Total}_{-}\text{Persons}_{-}\text{Vehicles} = [\text{Travel}_{-}\text{Vehicle}_{-}\text{Time}] \times \frac{\text{X}}{60} \times 3635 \text{ or } (\text{Y}) \ldots \ldots \ldots \ldots (i)
\]

The total persons in vehicles (i) during an hour is calculated by multiplying the above obtained result (i) with the number of minutes in an hour (60) and dividing the result by the total time (‘X’) it takes to travel along the road segment. Thus,

\[
[\text{Total}_{-}\text{Persons}_{-}\text{Vehicles}_{-}9_{-}10] = \text{Total}_{-}\text{Persons}_{-}\text{Vehicles} \times 60 / \text{X} \ldots \ldots \ldots \ldots (ii)
\]

Similarly Calculation is done for Pedestrians.

To get the total traffic in terms of people in vehicles as well as pedestrians along each segment during an hour, the following formula was used:

\[
[\text{Total}_{-}\text{Trafic}_{-}\text{Along}_{-}\text{Road}_{-}\text{Segment}_{-}\text{One}_{-}\text{Hour}] = [\text{Total}_{-}\text{Persons}_{-}\text{Vehicles}_{-}\text{One}_{-}\text{Hour}] + [\text{Total}_{-}\text{Persons}_{-}\text{Perdestrians}_{-}\text{One}_{-}\text{Hour}] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (iii)
\]

In order to get the number of people between two junctions, the results from (iii) need to be summed up and the same have been depicted along with other figures pertaining to peoples presence on roads (in terms of people standing/waiting – these figures are based upon field observation) within se results have been depicted hereafter in the table 6-8.

<table>
<thead>
<tr>
<th>#</th>
<th>Junction Name</th>
<th>Presence of People on ROAD Segments</th>
<th>Total People Present at on ROADS</th>
<th>Population distribution in BUILDINGS</th>
<th>Total FLOATING Population in/around BUILDINGS</th>
<th>Total Population between 09 to 10 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In/on Vehicles</td>
<td>Pedestrian s</td>
<td>Total</td>
<td>Number of People standing/waiting*</td>
<td>Residence s (1197 #) *2</td>
<td>Shops (39 #) *60</td>
</tr>
<tr>
<td>1</td>
<td>B-B5</td>
<td>3637</td>
<td>889</td>
<td>4526</td>
<td>60</td>
<td>4586</td>
</tr>
<tr>
<td>2</td>
<td>B-A</td>
<td>2302</td>
<td>548</td>
<td>2851</td>
<td>360</td>
<td>3211</td>
</tr>
<tr>
<td>3</td>
<td>A-A2</td>
<td>1947</td>
<td>270</td>
<td>2217</td>
<td>240</td>
<td>2457</td>
</tr>
<tr>
<td>4</td>
<td>A2-C2</td>
<td>252</td>
<td>90</td>
<td>343</td>
<td>180</td>
<td>523</td>
</tr>
<tr>
<td>5</td>
<td>C2-B5</td>
<td>935</td>
<td>336</td>
<td>1271</td>
<td>50</td>
<td>1321</td>
</tr>
<tr>
<td>Total</td>
<td>8826</td>
<td>1170</td>
<td>11208</td>
<td>840</td>
<td>10836</td>
<td>1285</td>
</tr>
</tbody>
</table>

Figure 6-8 Total persons present outside buildings (on road segments) and inside buildings

*: Number of People Standing/Waiting/Hawking has been multiplied by a conversion factor (assumed for the present study as 12; this factor has been considered with the basis that on an average, people standing at a particular junction will be there for an average of 5 minutes and then leave that junction).

#: Based upon the equation (b)
Multiplication of the total persons_vehicles with the total travel time from one junction to another gave the total persons in/on vehicles during a minute.

On similar lines, the total persons_pedestrians for one minute was also calculated by the following formula.

\[
\text{Total Person Pedestrians} = (\text{To From Pedestrian} \times \text{Travel Pedestrian Time}) + (\text{From to Pedestrian} \times \text{Travel Pedestrian Time})
\]

The summation of the Total_Persons_Vehicles and Total_Persons_Pedestrians gave the total number of people during a minute.

Thus, Total Population along any segment between 09-10 hours = [Total_Persons_Vehicles] + [Total_Persons_Pedestrians] (for example in case of segment B-B5 it is 64.42 persons - say 64 persons). Multiplying by 60 gave the hourly figures of people that were moving through each of the road segments in both directions.

Based upon the above process and calculations for each road segment; the following result was obtained which has been depicted in figure 6-9. The total persons in vehicles and pedestrians along
the 17 road segments comes to 12557 persons. From this, vehicles_persons comprise of 10117 whereas, the remaining 2440 persons are pedestrians (including hawkers and vendors).

Adding the above information previously obtained results on people’s presence within buildings and people standing at junctions; and again taking the example of 9-10 hours the final figures of people actually in the area (refer table 6-6) was obtained.

6.5. Summary

This chapter discussed about at how to arrive at the population distribution in an area and how the population distribution fluctuates to a great extent during different hours of the day and in various buildings occupancy types. This establishes the fact that Census sources are inadequate for exercises such as vulnerability analysis and that for population vulnerability assessment, the presence of people with varied demographic characteristics and living/working/studying/visiting in varied buildings occupancies needs to be looked into critically before embarking upon such as exercise. In the case study area one tenth of the population (during the time 09 to 10 hours) were found to be indoors and the remaining were outdoors which establishes the fact that there is a phenomenal difference in the people who are outdoors and those who are indoors.
7. Population Vulnerability Assessment and Upscaling at city level

7.1. Introduction

This chapter presents the population vulnerability aspect of the study which is based upon the results obtained in the previous two chapters. The population vulnerability due to buildings in Sector A has described so as to get an insight into the actual number of persons likely to be affected in case of an earthquake. Later in the chapter, the subject of scaling up such an exercise at the city level has been dealt with.

7.2. Population Vulnerability Assessment

Based upon the table in chapter 5, and taking the example in the present section specifically about the most vulnerable buildings (although similarly the population vulnerability exercises for buildings with low to medium vulnerability could also be carried out); it is seen that there are 44 buildings that are highly vulnerable to earthquakes and also have a high probability of collapse. The values of maximum probability have been used in case of buildings with high risk (the reverse order is true for buildings with low/medium risk) based on the table 5.10 in chapter 5 which provided an indication of the probability of total collapse of buildings with different wall materials; for example, Adobe+ Field Stone Masonry Buildings have the maximum probability of total collapse of 55, the corresponding figures for buildings with Brick in Mud (BM) is 41 and for Brick in Mud Well Built (BMW)/Brick in Lime/ Brick in Cement is 18.

7.2.1. Number of Severity of Casualties in case of a Scenario Earthquake

The number of people present in each of the above mentioned 44 buildings for various times of the day has been provided in the table 7.2. These figures have been arrived at by crossing the map of buildings with high to very vulnerability and the map showing the population presence for each hour of the day.

The following table provides a straight casualty rate that has been used by Islam, 2004. This table has basically been developed from HAZUS study. However, according to Islam 2004 it requires active consideration as to whether the rate is same for daytime or night time as people remain asleep at night hence probably have a lesser chance to survive than day time. Since the study area in terms of the type of buildings as well as socio-cultural context is relatively similar to that of Lalitpur in Nepal (the case study city for Islam’s (2004) study on Population Vulnerability) the %s of severity and injury levels have been directly adopted for calculation in the present study.
### Building Damage Level

<table>
<thead>
<tr>
<th>Injury Level (in %)</th>
<th>Severity 1</th>
<th>Severity 2</th>
<th>Severity 3</th>
<th>Severity 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial Damage</td>
<td>1</td>
<td>0.1</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Complete Damage</td>
<td>40</td>
<td>20</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

**Figure 7-1 Injury Severity Description**

*Source:* Islam, 2004

### 7.2.2. Number of People present in these buildings

Taking again the example of the population presence for the four time periods mentioned in section 6.3 in chapter 6, we can give a clear indication of the actual number of people within these buildings in Sector A as well as the number of severity and extent of casualties based upon Islam (2004).

<table>
<thead>
<tr>
<th>Particulars</th>
<th>01-02</th>
<th>09-10</th>
<th>14-15</th>
<th>19-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of People in Building</td>
<td>294</td>
<td>669</td>
<td>317</td>
<td>227</td>
</tr>
<tr>
<td>% of total residential population (1208 persons)</td>
<td>26.4</td>
<td>55.4</td>
<td>18.8</td>
<td>24.3</td>
</tr>
<tr>
<td>Severity 1 (40 %)</td>
<td>14</td>
<td>6</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Severity 2 (20%)</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Severity 3 (5%)</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Severity 4 (10%)</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total Population affected in buildings that are highly vulnerable and have a high probability of collapsing</td>
<td>26</td>
<td>11</td>
<td>24</td>
<td>33</td>
</tr>
</tbody>
</table>

**Figure 7-2 Number of People present in buildings and injury severity estimates**

*Note:* Figures in brackets indicate the injury level for various severities

Based upon Islam (2004)

The table above presents the number of people present in buildings at various time periods of the day and it is seen that during 09-10 hours, a figure equivalent to more that half of the total residential population in the sector is present within 44 (the buildings classified in section as having high to very high risk in case of an earthquake) of the 159 buildings in sector A that have been identified as risky. This is an clear indication of the huge extent of vulnerability of the population even though the figures of severity levels 1-4 seem to be in single digit % of the total ward population; however; the fact of the matter is that the buildings are vulnerable and in case of an earthquake, population loss or injury can occur the extent of which has been indicated in the above table. The above example taking only the high to very high risky buildings into account is intended to serve as an example of population vulnerability.

Population loss (in terms of number and severity of injury) due to presence of people outside the buildings as a consequence of buildings collapsing and road blockages occurring has not been discussed in the present report although this aspect can be explored in a further research works.
7.3. **Up scaling Population Vulnerability Exercise at City Level**

In order to upscale such a population distribution (by using results pertaining to population vulnerability such as those obtained from the present study); for determining building condition and their vulnerability and also the number and severity of casualties; two important inputs are a prerequisite. The first is the footprint map providing details of buildings and the second is the database on population and additional information on the buildings (that the population resides/works/studies/uses in) needs to be attached to such a map. The following sub-sections elaborate this aspect.

![Diagram](image)

**Figure 7-3 : Up scaling Population Vulnerability Exercise at City Level**

### 7.3.1. **Building Database Generation for the entire city**

As mentioned earlier, the MDDA has a digital footprint map in GIS environment – prepared for purposes such as use in Property Taxation; and the same should be the primary base for obtaining information on building footprints (and attributes) for the entire city. However, it should be noted that such a map should not be used prior to field ground thruthing as the footprint map would not be an updated one at the time of being used for other municipal duties and functions as well as other purposes such as research. The ward level building inspector of DMC along with community representatives (such as the Wardens and others in the community associated with the organizations such as the Civil Defence Organisation in the case of Dehradun city) could visit their respective wards and collect further inventory data (mentioned in the section later in 7.4.3). DMMC could provide training within or outside the framework of the GoI-UNDP UVERP.

### 7.3.2. **Potential Sources of Information from Community**

As discussed in the preceding sections about how data from CBOs (such as Civil Defence Organisation) can be used to actually pin point the population that resides in each building. This is
one organised and potential source of information that needs to be integrated with other objectives in Development Planning.

As such, the community has other sources of information at the grass root level. Such information can be community specific or even at a wider base. The more microscopic the information collection level, the more accurate it is likely to be. For example, in the case study ward, there are people of various communities residing (based upon religion or ‘mohalla’ wise) and for every festival or occasions (such as Jagrans – refer figure 6-4), there is a list of residents prepared (for purposes such as collection of donation, determining number of people likely to attend a function, etc.) and such information can be a very useful source for further application to other exercises.

However, the CBO such as Civil Defence needs to also look into expansion of the role of maintaining demographic details of the non-residential occupancy classes (such as shops, offices, etc.). Such information can be useful for many purposes such as population vulnerability.

7.3.3. Need for expansion of CBOs role towards preparedness from impacts of Hazards

The information from the CBO at Khudbura appears to be an important and potential source of database. Also the functions that the CBO carried out that are actually follow a community based mechanism are strongly related to not only defence purposes but can be expanded towards preparedness for disaster risk and management. However, for work to follow on these suggested lines, will this lead to the requirement of policy level interventions right at the Central Government level.

There is a need to provide a format for data collection and data sharing across the disciplines that can be involved in casualty estimation and on these lines further work can be taken for devising a database management format. Such a data format should be flexible enough to handle the currently available data, re-evaluate previously collected data and accept new data as they become available.

The Civil Defence Organisation data collection mechanism at sector level os a highly efficient and updated one and useful for a variety of purposes especially basic steps towards disaster mitigation and management such as vulnerability assessment. The organisation needs to formally be roped in along with other stakeholders such as the DMMC, the two ULBs (MDDA and DMC), NGOs, CBOs, professionals and interested individuals (representing the larger Civil Society); the UNDP-GoI’s UEVRP. A combines effort from all these stakeholders – the most important being the community will ensure the successful preparation and implementation of the DMP.

In terms of improvements of the data already being collected by the Civil Defence Organisation; the following are recommend as part of the present study:

- Provide two specific columns for the profession (e.g. housewife, student, working person, etc.) and address of work for all the household members and not only the household head. This would help in knowing the exact profile of a person based upon which the typical activity pattern profile can be obtained. According to the derived typical activity pattern (refer section 6-4), a rough picture of the presence of people in each category within all types of buildings and not only residential. In order to know details of the specific occupancy class and buildings that exist in each sector/ward; basic data such as building type – i.e. RCC, BMWB,
etc.; number of stories, occupancy class and the number of units (households and enterprise) would be required to be collected.
- City traffic department needs to undertake traffic counts with the help of school and the Government Polytechnic students as well as used of mechanised means) for availing traffic counts along roads – not only major roads but secondary and tertiary also.

7.3.4. Exploring other sources of data/information on population presence

Other sources of data/information on the population presence needs to be determined to be able to get a better idea (as compared to conventional census sources that are aggregated at the ward level). For example, a good source is the Uttranchal Power Corporation from where details of users and consumption of electricity in Dehradun Municipal Limits can be obtained.

7.4. Summary

This chapter dealt with population vulnerability aspect due to buildings stock condition in Sector A of the case study ward and the number of persons likely to be affected in case of an earthquake. The efforts that can be made in the context of the case study city for scaling up efforts such as that depicted in the present report has also been mentioned. In the backdrop of the present and previous chapters, the next chapter outlines the recommendations and conclusions of this research.
8. Conclusions and Recommendations

8.1. Conclusions

The broad conclusions of the report encompass a variety of subjects areas requiring development intervention however; all these are essentially in the framework of disaster risk assessment and population vulnerability reduction. In order to categorically state the conclusions and recommendations the same have been presented hereafter point wise.

8.1.1. Building Vulnerability Analysis

- The results of the building analysis based upon the GIS based approach brought out the fact that 44 buildings are high and very high risk categories in case if an intensity of VIII earthquake is felt in the study area. The community based mapping of risky buildings resulted in identification of 24 buildings in the risky category.
- Community Based Analysis reinforces the results obtained from technocratic (for example GIS) based analysis on Building Vulnerability.
- Communities are the ‘Sources’ as well as the ‘Sinks’ of the data/information as for example in assessment of their vulnerability, community health programmes such as immunization, etc. Communities are a good source of inputs on their vulnerabilities and can provide ‘value added’ information to technocratic (e.g.GIS) based analysis and at the same time it is important to recognise the fact that the community is able to give a clear output of what was asked from them during the risk (and resource mapping exercise) and can contribute to the results that a GIS based analysis brings out.
- The outputs of the GIS based analysis as well as the community based approach of building vulnerability assessment is useful for obtaining a wider array of results which can be beneficial to the Urban Local Body when it comes to actual identification of buildings that need to be identified as requiring attention (such as seismic strengthening).

8.1.2. Population Distribution and Vulnerability

8.1.2.1. Population Distribution within buildings

- Population distribution (from which densities can be calculated) vary and fluctuate to a great extent during different hours of the day and in various buildings occupancy types. Hence Census sources are outdated as well inadequate as well as relatively outdated for vulnerability analysis.
• The population activity patterns for holidays were not captured to an extent and hence there is a need to look at methods of capturing peoples activity patterns during such days.

8.1.2.2. Population Distribution outdoors

• From the study it is noted that there is a ten fold difference between the populations outdoors as compared to those who are indoors. Hence calculating population distribution and their vulnerability only for indoor environment would not be sufficient enough to actually obtain a true picture of where and how many people are at a particular place/road at any time of the day.

8.2. Recommendations

8.2.1. Need for expansion of CBOs role towards preparedness from impacts of Hazards

• The information from the CBO at Khudbura appears to be an important and potential source of database. The functions that the CBO carried out is strongly related to not only civil defence purposes but the role of the CBO can be expanded towards preparedness for disaster risk and management. However, for work to follow on these suggested lines, implies the requirement of policy level interventions right at the Central Government level. The Civil Defence organisation needs to formally be roped in along with other stakeholders such as the DMMC, the two ULBs (MDDA and DMC), NGOs, other CBOs, professionals and interested individuals (representing the larger Civil Society) and; the UNDP-GoI’s UEVRP. A combined effort from all these stakeholders – the most important being the community will ensure the successful preparation and implementation of the DMP.

• There is a need to provide a format for data collection and data sharing across the disciplines that can be involved in casualty estimation. Such a data format should be flexible enough to handle the currently available data, re-evaluate previously collected data and accept new data as they become available.

• The Civil Defence Organisation data collection mechanism at sector level is a highly efficient and updated one and useful for a variety of purposes especially basic steps towards disaster mitigation and management such as vulnerability assessment.

• City traffic department needs to under take traffic counts with the help of school and the Government Polytechnic students as well as used of mechanised means) for availing traffic counts along roads – not only major roads but secondary and tertiary also.
8.2.2. Exploring other sources of data/information on population presence

- Other sources of data/information on the population presence needs to be determined to be able to get a better idea (as compared to conventional census sources that are aggregated at the ward level).

8.2.3. Conduction of detailed population distribution exercise for population outdoor environment

- Population loss (in terms of number and severity of injury) due to presence of people outside the buildings as a consequence of buildings collapsing and road blockages occurring needs to be looked into in greater detail in further research works.
- The population activity patterns for holidays were not captured to an extent and hence there is a need to look at methods of capturing peoples activity patterns during such days.
References


Appendix I Details of Uttrakashi (1999) and Chamoli (1991) Earthquakes

(Source: Ghildial, 2004)

Uttarkashi Earthquake, 1991
A earthquake of 6.6 magnitude rocked the Uttarkashi and the surrounding areas on October 20th, 1991 at 02.53 A.M. when people were asleep. The epicenter of the earthquake was near Uttarkashi town. This caused widespread damages in many districts of Uttaranchal., i.e. Uttarkashi, Tehri, Rudraprayag, and Chamoli. About 723 people lost their lives and thousands got injured and 70,000 houses were damaged fully or partially. Many villages were wiped out around Bhatwari-Maneri along Bhagirathi valley, Budhakedar- Chamiala in Balganga valley, Ghansayli in Bhilngana valley, and GuptkashiOokhimath in Mandakini valley. Uttarkashi town was badly damaged. It was a shallow to intermediate focus earthquake and Agora, a small village near Uttarkashi was its epicenter.

The devastating earthquake rendered all the infrastructural facilities like roads, bridges and communication network defunct for a longtime and no rescue and relief operations could be started immediately. The local civil administration was unable to handle the situation and the army and other para - military forces were summoned and pressed into action. The voluntary organizations active in the region were of extreme help in the distribution of food and clothing and about 1200 NGO's reportedly reached from various places as rescue help.

<table>
<thead>
<tr>
<th>Destruction caused</th>
<th>Uttarkashi, Tehri, Rudraprayag &amp; Chamoli</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affected Districts</td>
<td>More than 720</td>
</tr>
<tr>
<td>Deaths</td>
<td>723</td>
</tr>
<tr>
<td>Injured</td>
<td>5000 approx.</td>
</tr>
<tr>
<td>Affected village</td>
<td>2000</td>
</tr>
<tr>
<td>Affected Population</td>
<td>4.5 lakhs</td>
</tr>
<tr>
<td>Totally collapsed houses</td>
<td>25000+</td>
</tr>
<tr>
<td>Semi-collapsed with cracks</td>
<td>75000+</td>
</tr>
<tr>
<td>Collapsed Schools/Inter Colleges</td>
<td>630</td>
</tr>
<tr>
<td>Animals killed</td>
<td>4000+</td>
</tr>
<tr>
<td>Total loss</td>
<td>Rs. 370 + crores</td>
</tr>
</tbody>
</table>

Note: One Crore is Rs. 10 million

Damage due to Uttrakashi Earthquake, 1991

Chamoli Earthquake, 1999
On 29th March, 1999 at 12.35 a.m. a stronger earthquake measuring 6.8 on the Richter scale struck near the town of Chamoli. The epicenter of this earthquake was approximately 10 kilometres away from the township. It was an unprecedented earthquake which caused extensive damage to life and property of the people of Chamoli, Gopeshwar, Nandprayag, Rudraprayag, Joshimath, Ookhimath and other parts of the Garhwal and Kumaun Himalayas. More than 100 people were killed and about 300 injured. In the district of Chamoli alone 90% of the houses were totally damaged. Other highly vulnerable areas of the Kumayun Himalaya, i.e. Munsyari, Dharchula and Bageshwar were also reportedly affected. The following is the table reflecting the account of damage caused due to Chamoli earthquake.

It was observed in Chamoli that unengineered building were the ones which got maximum damage, compared to engineered building which somehow withstood the quake. The stone based buildings, which are very popular in the region are very dangerous and a threat to life. The situation demands the urgent need for engineering inputs for design of earthquake resistant buildings, and dissemination of such techniques to the masses for construction activities usually carried out informally. It is also a fact that some very old structures also survived, which speak about traditional wisdom of the people, in construction methods, responsive to locational needs.

Note: One Crore is Rs. 10 million
## Appendix II  Road Survey (Traffic Volume and Characteristics) Form

<table>
<thead>
<tr>
<th>Pocket Number</th>
<th>Road ID</th>
<th>Segment ID</th>
<th>Direction To</th>
<th>Time</th>
<th>Road Width (m)</th>
<th>Car</th>
<th>Taxi</th>
<th>Vehicles Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tempo</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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Time: 
Date: 
Name of Surveyor:
## Appendix III Building Survey Questionnaire

<table>
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<tr>
<th>Pocket Number</th>
<th>Building ID</th>
<th>Age of building:</th>
<th>Number of Stories</th>
<th>GF</th>
<th>G+1</th>
<th>G+2</th>
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<table>
<thead>
<tr>
<th>Detached/Semidetached</th>
<th>Detached</th>
<th>Semidetached</th>
<th>Structure</th>
<th>Framed</th>
<th>Load bearing</th>
<th>Number of Units/Families staying inside the building</th>
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</table>

### Building Material

<table>
<thead>
<tr>
<th>Wall</th>
<th>Stone with mud</th>
<th>Stone in lime</th>
<th>Stone in cement</th>
<th>Brick in mud</th>
<th>Brick in lime</th>
<th>Brick in cement</th>
<th>Tin</th>
<th>Wood</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>RBC (\text{(Lantal)})</td>
<td>RCC</td>
<td>Tin</td>
<td>Wood</td>
<td>Thatch</td>
<td>Tarpolene</td>
<td>Plastic</td>
<td>Others</td>
<td></td>
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<tr>
<td>Floor</td>
<td>PCC</td>
<td>Mosaic</td>
<td>Marble</td>
<td>\text{Kachha-mud}</td>
<td>Brick</td>
<td>Stone</td>
<td>Others</td>
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</table>

### Condition of building

<table>
<thead>
<tr>
<th>Condition of building</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
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</tbody>
</table>

### Cracks visible

<table>
<thead>
<tr>
<th>Cracks visible</th>
<th>Horizontal cracks</th>
<th>Diagonal cracks</th>
<th>Vertical cracks</th>
<th>Separation of walls at T and L junction</th>
<th>No</th>
</tr>
</thead>
</table>

### Condition of Walls

<table>
<thead>
<tr>
<th>Condition of Walls</th>
<th>Bulging of walls</th>
<th>Delamination of walls</th>
<th>Tilting of walls</th>
<th>Dampness in wall</th>
<th>None</th>
</tr>
</thead>
</table>

### Building Use

<table>
<thead>
<tr>
<th>Building Use</th>
<th>1 Residential</th>
<th>2 Commercial</th>
<th>3 Residential + Commercial</th>
<th>4. Clinic</th>
<th>5. Industrial</th>
<th>6. School</th>
<th>7. Office (Government/Public Sector)</th>
<th>8 Office (Private Sector)</th>
<th>9 Other</th>
</tr>
</thead>
</table>

### Particular use of building

<table>
<thead>
<tr>
<th>Particular use of building (Shop, Store, Warehouse etc.)</th>
<th>Open Space</th>
<th>Process of building construction</th>
<th>Shape of the building block in Plan (encircle the appropriate number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there open space connected with the building block?</td>
<td>Yes 1</td>
<td>Owner built 1</td>
<td>1 Square (L&lt; =3B)</td>
</tr>
<tr>
<td></td>
<td>If yes: Front</td>
<td>Purchased 2</td>
<td>3 Narrow Rectangular (L&gt; 3B)</td>
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<td></td>
<td>Back</td>
<td>Constructed by contractor</td>
<td>4 T-Shaped Building</td>
</tr>
<tr>
<td></td>
<td>Side : Left</td>
<td></td>
<td>5 L-Shaped Building</td>
</tr>
<tr>
<td></td>
<td>Side : Right</td>
<td></td>
<td>6 U-Shaped Building</td>
</tr>
<tr>
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<td>7 H-Shaped Building</td>
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<td></td>
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<td></td>
<td>8 Building with Central Courtyard</td>
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<td>9 Trapeziodal</td>
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<td></td>
<td>10 Other</td>
</tr>
<tr>
<td></td>
<td>No 2</td>
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<tr>
<td></td>
<td>Building Location</td>
<td></td>
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<tr>
<td></td>
<td>Flat land 1</td>
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<tr>
<td></td>
<td>Gentle Slope 2</td>
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<td></td>
<td>Steep Slope 3</td>
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</table>
## Appendix IV Household/Enterprise Profile and Activity Survey

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Name</th>
<th>Age</th>
<th>Sex</th>
<th>Marital Status</th>
<th>Education Level</th>
<th>Occupation</th>
<th>Disability</th>
<th>Time use</th>
<th>Total time of absence</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

* Time use in terms of where is a person during the given time period (H=Home, O=Office, S=School, C=College, P=Purchasing in pucca structure, PK=Purchasing in Open Structure, T=Traveling on City Road, OFS=Out of Town)

(Location for each of the below mentioned options needs to be filled in also) Also, to be indicated will be whether the person is inside the ward or outside (e.g. O-I or O-o)

# Based upon statistical analysis

### Codes

**Age**
- 0-4: 1
- 5-9: 2
- 10-14: 3
- 15-19: 4
- 20-24: 5
- 25-29: 6
- 30-39: 7
- 40-44: 8
- 45-49: 9
- 50-59: 10
- 60-64: 11
- 65-69: 12
- 70-74: 13
- 75-80: 14
- 80-85: 15
- 85+: 16

**Sex**
- Male: 1

**Marital Status**
- Married: 1
- Unmarried: 2
- Widowed/widower: 3
- Divorced: 4

**Education level**
- Illiterate: 1
- Upto class 5: 2
- Upto class 7: 3
- Upto class 10: 4
- Upto class 12: 5
- College: 6
- Postgraduate: 7

**Occupation**
- Housewife: 1
- Service/Job: 2
- Business: 3
- Studying: 4
- Homebased Worker: 5
- Teacher: 6
- Labourer: 7

**Disability**
- None: 1
- Physical: 2
- Mental: 3
- Both Physical and Mental: 4
Appendix V: Database format of Building Survey Information

<table>
<thead>
<tr>
<th>Record</th>
<th>ID</th>
<th>ID</th>
<th>Shape</th>
<th>Shape</th>
<th>Structure</th>
<th>Num, Surname</th>
<th>House Id</th>
<th>Remarks</th>
<th>Area, A</th>
<th>Perimeter, Meter</th>
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</tbody>
</table>

Record 1-10: Show all Selected Records (10 of 10 Selected)
Appendix VII Building Vulnerability Analysis

8.4.

8.5.

8.6.
## Appendix VII Recoding of Sub Types of Building Condition Parameters

<table>
<thead>
<tr>
<th>#</th>
<th>Parameters</th>
<th>Sub Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of stories</td>
<td>1 2 10</td>
</tr>
<tr>
<td></td>
<td>(Actual Number of Stories)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Detachment</td>
<td>Detached 1 Semi - Detached 2</td>
</tr>
<tr>
<td>3</td>
<td>Building Cracks</td>
<td>None (1) Diagonal (2) Horizontal and Vertical (3) Vertical (4) Separation of walls at T and L junction (5) Horizontal, Diagonal, Vertical and Separation of walls at T and L junction (6) Vertical, Diagonal and Separation of walls at T and L junction (7) Vertical, Diagonal and Separation of walls at T and L junction (8)</td>
</tr>
<tr>
<td>4</td>
<td>Building Wall Condition</td>
<td>None – 999 (1) Dampness – 4 Delamination – 2, 24 (3) Bulging of Walls – 1 (4) Tilting of Walls – 3 (5) Vertical, Diagonal and Separation of walls at T and L junction (6) Vertical, Diagonal and Separation of walls at T and L junction (7) Vertical, Diagonal and Separation of walls at T and L junction (8)</td>
</tr>
<tr>
<td>5</td>
<td>Building Shape</td>
<td>Square – 1 (1) Rectangle – 2 (2) Other shapes : Narrow Rectangular (L&gt;3B), T shaped, L shaped, U shaped, H shaped, trapezoidal, etc. (3)</td>
</tr>
<tr>
<td>6</td>
<td>Slope of Terrain</td>
<td>Flat 2 Gentle 3 Steep</td>
</tr>
</tbody>
</table>
Appendix VIII: Population Vulnerability Analysis
### Appendix IX: Number of Students in Schools within Sector A and Schedule of Religious Place (Mosque)

#### Number of Students in Schools within Sector A

<table>
<thead>
<tr>
<th>School</th>
<th>Number of Children and Staff</th>
<th>Summer (October to February)</th>
<th>Winter (October to February)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinder Garden (Play Group to 5th Standard)</td>
<td>260</td>
<td>08.30-13.30</td>
<td>08.00-13.30</td>
<td>May to June</td>
<td>November (15 days)</td>
</tr>
<tr>
<td>Model School</td>
<td>370</td>
<td>08.00-13.15</td>
<td>08.30-13.30</td>
<td>May to June</td>
<td>November (15 days)</td>
</tr>
<tr>
<td>City Board School</td>
<td>390</td>
<td>08.00-13.00</td>
<td>10.00-16.00</td>
<td>May to June</td>
<td>November (15 days)</td>
</tr>
</tbody>
</table>

*Source: Field Discussions*

#### Number of Persons visiting Religious Places

<table>
<thead>
<tr>
<th>Type of Religious Place</th>
<th>Number of Persons visiting the Place</th>
<th>Timing of Peoples Presence</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosque</td>
<td>Average varies from 50-100 persons</td>
<td>05.00  06.00  14.00  16.30 18.30 21.00</td>
<td>After Id festival about 20 children come to learn Namaj and Urdu language between 07.00am to 11.00am and 4.00 to 5.30 am</td>
</tr>
<tr>
<td>Temple</td>
<td>150-200</td>
<td>06.30  07.00</td>
<td>* Sporadic Presence for a few minutes</td>
</tr>
</tbody>
</table>

*Source: Field Discussions*
Appendix X : Average % & number of people present in residence(HH), shop, other units & schools during the day

| Day (Week Day) | Average HH/Enterprise/ School Size | 04 to 05 | 05 to 06 | 06 to 07 | 07 to 08 | 08 to 09 | 09 to 10 | 10 to 11 | 11 to 12 | 12 to 13 | 13 to 14 | 14 to 15 | 15 to 16 | 16 to 17 | 17 to 18 | 18 to 19 | 19 to 20 | 20 to 21 | 21 to 22 | 22 to 23 | 23 to 24 | 00 to 01 | 01 to 02 | 02 to 03 | 03 to 04 |
|---------------|-----------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| HH (A) %      |                                   | 100      | 98       | 90       | 94       | 81       | 50       | 39       | 30       | 31       | 36       | 63       | 80       | 78       | 61       | 56       | 65       | 71       | 89       | 88       | 92       | 98       | 98       | 98       | 98       |
| HH (B) #      |                                   | 5.49     | 5.4      | 4.9      | 5.2      | 4.5      | 2.8      | 2.2      | 1.7      | 1.7      | 2.0      | 3.5      | 4.4      | 4.3      | 3.4      | 3.1      | 3.6      | 3.9      | 4.9      | 4.8      | 5.1      | 5.4      | 5.4      | 5.4      | 5.4      |
| Shop(A) %     |                                   | 100      | 27.9     | 40.9     | 45.9     | 75.3     | 87.1     | 87.1     | 63.5     | 69.4     | 69.0     | 75.3     | 87.3     | 87.3     | 63.5     | 17.1     | 11.8     | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      |
| Shop(B) #     |                                   | 1.4      | 0.4      | 0.6      | 0.7      | 0.7      | 1.1      | 1.1      | 1.2      | 0.9      | 0.9      | 0.9      | 1.1      | 1.2      | 1.2      | 0.9      | 0.3      | 0.2      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      |
| Other Units(A)% |                                 | 100      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      | 3.0      |
| Other Units(B) # |                                  | 6.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      | 5.0      |
| School(A) %   |                                   | 100      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      | 0.0      |
| School(B) #   |                                   | 290      | 0        | 0        | 2        | 50       | 300      | 300      | 300      | 300      | 300      | 300      | 300      | 250      | 30       | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        |
| Total Population Present in all above building occupancies | 1204.5 | 1124 | 1175 | 1098 | 762 | 1284 | 1178 | 1188 | 1229 | 1419 | 1221 | 1135 | 992 | 911 | 906 | 962 | 1102 | 1087 | 1124 | 1189 | 1189 | 1189 | 1189 |
| % of Total Recorded (As per Civil Defense Register)Population (1208 persons) | 99.7 | 93.1 | 97.3 | 90.1 | 63.1 | 106 | 98.3 | 98.1 | 102 | 117.5 | 101 | 93.9 | 78.9 | 75.4 | 74.9 | 79.6 | 91.2 | 90.0 | 93.0 | 98.4 | 98.4 | 98.4 | 98.4 |

(A) : % Presence of People in a building occupancy (residence, shop, other units and school) at different hours of the a week day

(B) : Average Number of Persons in building occupancy residence, shop, other units and school)
Appendix XI  Road Population Distribution Analysis
Appendix XI: Road Population Distribution Analysis

......continued from previous page
### Appendix XII  Attributes of Road Section in Geometric Network

<table>
<thead>
<tr>
<th>Attributes of Road Segments</th>
<th>Total_Person_VehArea</th>
<th>Total_Person_Production</th>
<th>Total_Person_VehAcc_Hour_Area</th>
<th>Total_Person_Production_Hour_Area</th>
<th>Total_Traffic_Volume_Road_Segment_Hour_Area</th>
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<td>252.342</td>
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</tr>
</tbody>
</table>
End Notes:

i Mr.Rajiv Ranjan and Ms.Anasuya Baruua, M Sc Students from Indian Institute of Remote Sensing (IIRS), Dehradun.

ii According to the Vulnerability Altas of India, Zone IV is second in severity to zone V and is referred as ‘high damage risk zone’. Zone V covers the areas liable to seismic intensity IX and above on Modified Mercalli Intensity scale – this is the most severe seismic zone and is referred as very ‘high damage risk zone’.

iii Sector : The Civil Defense Organisation – a semi government organization functions at the community level and for it’s functioning has divided the entire city into sectors. The present case study ward has five sectors.

iv The Series and Tables are : A Series: Population Tables; B Series: Economic Tables; C Series: Socio - Cultural Tables; D Series: Migration Tables; F Series: Fertility Tables; H Series : Housing and Household Amenities and; SC ST Series : Tables on Scheduled Castes and Scheduled Tribes.

v The second phase would involve US $5 million from UNDP core resources, US $16 million have been confirmed from non-core sources and US $11 million would be required to be mobilized jointly by GoI and UNDP.

vi The criteria for selection of the 38 cities was that of location in seismic zone 3, 4 and 5 with a population of more than half a million.


viii The examples of occupancy classes are residential, commercial, industrial, agriculture, regional, non/profit, government, education – within which are specific classes.

ix Examples of Model building types are for Wood, Light frame, steel moment frame, concrete moment frame, mobile homes, etc.

x Groups of states are based upon the regional distribution of states e.g. West Coast, East Coast, etc.

xi Essential facilities such as hospitals, police stations, fire stations and schools

xii Census tract are division of land that are designed to contain 2500-800 inhabitants with relatively homogeneous population characteristics, economic status and living conditions (FEMA, 1999).

xiii Default square footage calculated by SFI=UD*CF where SFI= Building square footage for an occupancy class; UD=Unit of data for that occupancy class; CF=Conversion factor for that occupancy class.

xiv RADIUS is a program launched by the United Nations and the methodology is the outcome after the project was worked in selected nice case study cities around the world.

xv The ground is classified as hard rock, soft rock, medium soil and soft soil and the corresponding fixed amplification factor is considered for probable amplification.

xvi Building classification is based on the common building types in Latin American /countries (e.g.RES1 is the code for informal construction – mainly slums, row housing, etc. made from unburned bricks, mud mortar, loosely tied walls and roofs.

xvii Building types such as adobe, brick masonry with mud joints, brick in cement and RCC buildings.

xviii Institutions such as The Indian Military Academy, The Forest Research Institute, The Oil and Natural Gas Commission, The Survey of India - to name a few are located in Dehradun.

xix The Doon valley is bounded by the lesser Himalayan rocks in the north, the Shivaliks in the south, traversely bordered by Ganga in the south-East and Yamuna in the north-west and forms intermontane valley ecosystem extending from 29°-55’ – 30° 30’ N Latitude and 77° 35’ – 78° 20’ E longitude.

xx The delineation nom is that any area above 600 meters above mean sea level be classified as hilly.

xxi Nallahs are small rivulets often getting polluted due to dumping of sullage and solid waste from settlements/cities.

xxii The entire state of Uttranchal is a tourist destination with hill stations and religious places spread over the state. A lot of tourists use the city as a base to travel to these other places of tourist interest.

xxiii The cities urban agglomeration comprises of Dehradun Municipal Area, the area under the Forest Research Institute, Adhoiwala out growth, Dehradun and Clement town cantonments and Rajpur town.

xxiv There were 34 wards in 1991 within the municipal limits. The total population was 270159 and the number of households was 53438 making the average household size at city level as 5.06 persons per household.

xxv Uttranchal was earlier part of Uttar Pradesh. Uttranchal became a separate state in the year 2000.

xxvi Uttranchal state is very susceptible to earthquakes due to the tectonic activities that take place with the continuous mounting pressure of the Indian plate in Tibetan plate which is still going on in this part of
Himalayas. The statistical data in the north-eastern part of Uttarakhand Himalaya shows that most of these earthquakes have taken place along 3 major thrusts/fault zones (a: MBT (Main Boundary Thrust), which demarcates Sivalik foot hills from the rest of Himalayas; b: MCT (Main Central Thrust), demarcates Central Himalayas and the Lesser Himalayas; and: c: CCT (Central Centre Trust), separating Central Himalayas from Tibetan Himalayas) (Ghildial, 2004).

Organisations contacted were: In Dehradun the MDDA (The MDDA has a digital footprint map – prepared for Property Taxation Purposes; however, the same was not available), IIRS DMMC, City Managers Association - Uttarchal Chapter, Survey of India; in Delhi the School of Planning and Architecture Library, the National Institute of Disaster Management; at Ahmedabad the School of Planning Library and; at Gandhinagar the Gujarat State Disaster Management Agency.

Predominant roof materials in India according to the Census of Housing (1991) are: Pitches Roofs including tiles, slate or shingle. Corrugated iron, zinc or other metal sheets; Asbestos cement sheets; thatch, grass, leaves, bamboo, etc. Flat roofs including brick, stone and lime; reinforced brick concrete/reinforced cement concrete.

Predominant wall materials in India according to the Census of Housing (1991) are: Mud, unburnt bricks, stone laid in mud or lime mortar; burnt bricks laid in cement, lime or mud mortar; cement concrete; wood or ekra walling; corrugated iron, zinc or other metal sheets, grass, leaves, reeds or bamboo or thatch and others.

Chowk means cross roads in Hindi.

Analysis considering further sub-division of the homogenous units would lead to more detailed distribution of population as well as pin-point location of casualties (Guragian, 2004).

Republic Day (January 26), Holi (usually in March), Republic Day (August 15), Gandhi Jayanti (October 2), Diwali (October end or Mid November), Eid-Ul-Fitr and Guru Nanak Jayanti.

The Festival is known as a festival of colours and marks the harvest time (it usually falls in March).

The main locations in the sectors under Post no.8 are the Gauri Shankar Temple, the Shiv Temple, the Gurudwara Sahib, Rawal Radios, Life line Medicos, Dr. Shivdas House, Shri P.G.C.Modi, Shri Guru Nanak Mahila Inter College, two Pulse Polio Camp locations and Basic Junior High School.

The general relation of Trifunac & Brady (1975) is:

\[ MMI = \frac{1}{0.3}\log(\frac{PGA*980}{10}) - 0.014 \]

Standardisation was done by applying the formula: \( \text{Score} = \frac{\text{Score-lowest}}{\text{highest score-lowest score}} \)

Most of the houses do not have much open space within their compound - i.e. sufficient enough for children to play and due to lack of official play grounds for general public.

There are exceptions (with respect to peoples dinner time) - such as people who follow religion strictly for example, in case of people following Jainism many have dinner before sunset.

Mostly shops do not have adequate space for people to walk in and hence purchasing is done over the counter with the customer standing outside the shop and the shop keeper inside the shop.

There is a trust operated by the Jhanda Darbar, this trust is established in memory of the founder of Dehradun – Guru Ram Rai. The trust owns a considerable property share in the city and particularly in Khudbura (where the city was founded), infact many shops and buildings in Khudbura have been given on rent to persons some of whom were surveyed for determining their activity patterns. The trust also owns the most dilapidated building (identified as having highest vulnerability) in the building vulnerability analysis.

The Jain Temple, Sharumbhra Deve’s Temple, Ganga Prachin Temple, Radha Krishna Temple, Prithvi nath Temple and those of the Sikhs, the Jhande Saheb’s Temple and that of the Sai Baba Temple.

Mohalla (a Hindi word) is usually a group of buildings/houses along a certain street or cul-de-sac; usually people in one mohalla have the same socio-economic characteristics although this may be not a hard and fast characteristics.