Chapter 3

Vulnerability Analysis

CHAPTER 3 VULNERABILITY ANALYSIS

3.1 Hazard Assessment

3.1.1 Earthquake

1) Hazard Assessment in Colombia

In 1996 the Seismic Hazard Maps for the territory of Colombia for based on the Colombian Standard for Earthquake Resistant Construction were made by the Colombian Association of Earthquake Engineering, the Los Andes University and INGEOMINAS.

The hazard assessment study used the seismic event catalogue database containing 11,088 events, and evaluated the seismic activities of 32 seismic faults identified.

Together with the available historical information of past earthquakes, they the study also prepared a map of the effective peak acceleration with over 10% probability of exceeding of 10% in 50 years (Aa) for all the territory of Colombia, and damage threshold acceleration to be used in the design of essential facilities (Ad), which is compatible with the requirements of the Colombian standard.

As the result, the territory of Colombian is categorized into nine zones according to the expected maximum acceleration (Aa) and shown in Figure 3.1.1. The potential of seismic hazards in the Study Area is categorized in the medium level zone and the Aa and Ad values of the city and municipalities are shown in the following Table 3.1.1.

Table 3.1.1 Aa and Ad by City/Municipality in the Study Area

Municipality	Aa (g)	Ad	Hazard level zone
Bogota	0.2	0.04	Medium
Chia	0.2	0.04	Medium
Cota	0.2	0.04	Medium
La Calera	0.2	0.04	Medium
Facatativa	0.2	0.04	Medium
Funza	0.2	0.04	Medium
Madrid	0.2	0.04	Medium
Mosquera	0.2	0.04	Medium
Soacha	0.2	0.04	Medium

Source: Estudio General de Amenaza Sismica de Colombia, AIS, 1996

Source: Estudio General de Amenaza Sismica de Colombia, AIS, 1996

Figure 3.1.1 Zones for Expected Maximum Acceleration in Colombia

2) Earthquake Hazard Assessment in Cundinamarca

The Cundinamarca government and INGEOMINAS studied on the environmental disasters in Cundinamarca for the period of 1923-1997. The events reported in the major newspapers in Colombia have collected and studied. The results are summarized and shown in Table 3.1.2. Among the environmental disasters, earthquakes occurred 68 times and the event that caused the biggest damage was in 1923.

Table 3.1.2 Human Damage Due to Ambient Disaster in Cundinamarca

		Human damage		
Event type	No. of event	Dead	Injured	Affected
Earthquake	68	40	107	915
Innudation	248	16	18	514,931
Flood	57	82	28	5,933
Fire	46	8	1	1,550
Contamination	11	0	0	0
Landslide	121	783	33	9,719
Hurricane	20	4	13	2,001
Dries	16	0	0	0
Tempest	60	13	7	795
Total	647	946	207	535,844

Source: Catalogo de desastres ambientales de Cundinamarca,

Gobernación de Cundinamarca, INGEOMINAS, 1997

Table 3.1.3 Summary of Damage Due to Earthquakes by Municipality

		Human damage			Property damage							
Municipality	**No. Of event**	**Dead**	**Injured**	**Evacuated**	**Roads**	**Pub. Services**	**Life lines**	**Buildings**	**Farmland**	**Forests**	**Domestic animals**	**Others**
Bogotá City	29	25	102	900	2	2	2	10	1	1	0	2
Chía	2							1				
Cota												
Facatativá	1							1				
Funza												
La Calera												
Madrid												
Mosquera												
Soacha	2								2			
Total	34	25	102	900	2	2	2	12	3	1	0	2
Cundinamarca	68	40	107	915								

Source: Catalogo de desastres ambientales de Cundinamarca, Gobernación de Cundinamarca, INGEOMINAS, 1997

Besides, the Cundinamarca government has a "Map of is-acceleration in Cundinamarca," based on the result for nation wide study of seismic hazard by INGEOMINAS in 1996. However, a geological model for micro zoning in Cundinamarca is yet to be made.

3.1.2 Landslide

1) Hazard Area

(1) Data

The Study Team has prepared a datasheet form to compile landslide disasters in the past five years and to identify hazardous slopes at present in the Study Area. The datasheet covers place and date, if recorded, and type of disaster, trigger, inherent causes, activity rate, and damages (human and property or potential objects to be protected). It also includes responses after disaster and risk evaluation in terms of urgency and scale for objects to be protected. The "diagnosis" forms documented through field observation by DPAE was used as raw data in Bogotá. Articles in major newspapers are sources of information for the eight municipalities in Cundinamarca.

Prior to the field survey the Study Team made interpretation of aerial photographs taken in 1993, 1994, 1996, 1997, and 1998 to identify hazardous slopes.

Also the satellite 3D image taken on March 2001 were used to study on changes in landform, vegetation and landslides after 1998. The satellite images were taken by ASTER (Advanced Space borne Thermal Emission and Reflection radiometer), using visible band with a resolution of 15m on ground surface. The satellite images were used to supplement the aerial photograph information.

The field survey of typical sites were conducted to verify the status, and to check the data and the results of photo interpretation.

(2) Evaluation

The Study Team assessed the potential risks of the identified sites in case of a slope disaster based on diagnostic documents by DPAE and through filed survey.

The principal factor used in evaluation is urgency to mitigate human damages by non-structural measures like evacuation. The secondary factor is scale of object to be protected, whose damage is difficult to be avoided by non-structural measures.

Principal factor: Urgency for damage mitigation:

- The slope disaster would claim casualties.
- The slope disaster would cause damages within several days after its occurrence.

Secondary factor: Scale of potential damages:

- The slope disaster would affect more than two objects for prevention.
- The slope disaster would affect one object for protection or cause only insignificant damages.

Using above-mentioned two factors, the hazardous slope areas are classified into the three grades as shown in Table 3.1.4.

Table 3.1.4 Assessment of Hazardous Slope Classification

Urgency of evacuation	Scale of damage	Influential to multiple and large facilities	Influential to single and/or minor facilities
		a	b
Urgent	A	Aa→Grade 1	Ab→Grade 1
Dangerous in a few days after disaster	B	Ba→Grade 2	Bb→Grade 3

Basic ideas for future attention are described as follows:

Grade 1 (Aa, Ab): Structural measures or relocation of inhabitants are needed.

Grade 2 (Ba): Some structural and/or non-structural measures would be required.

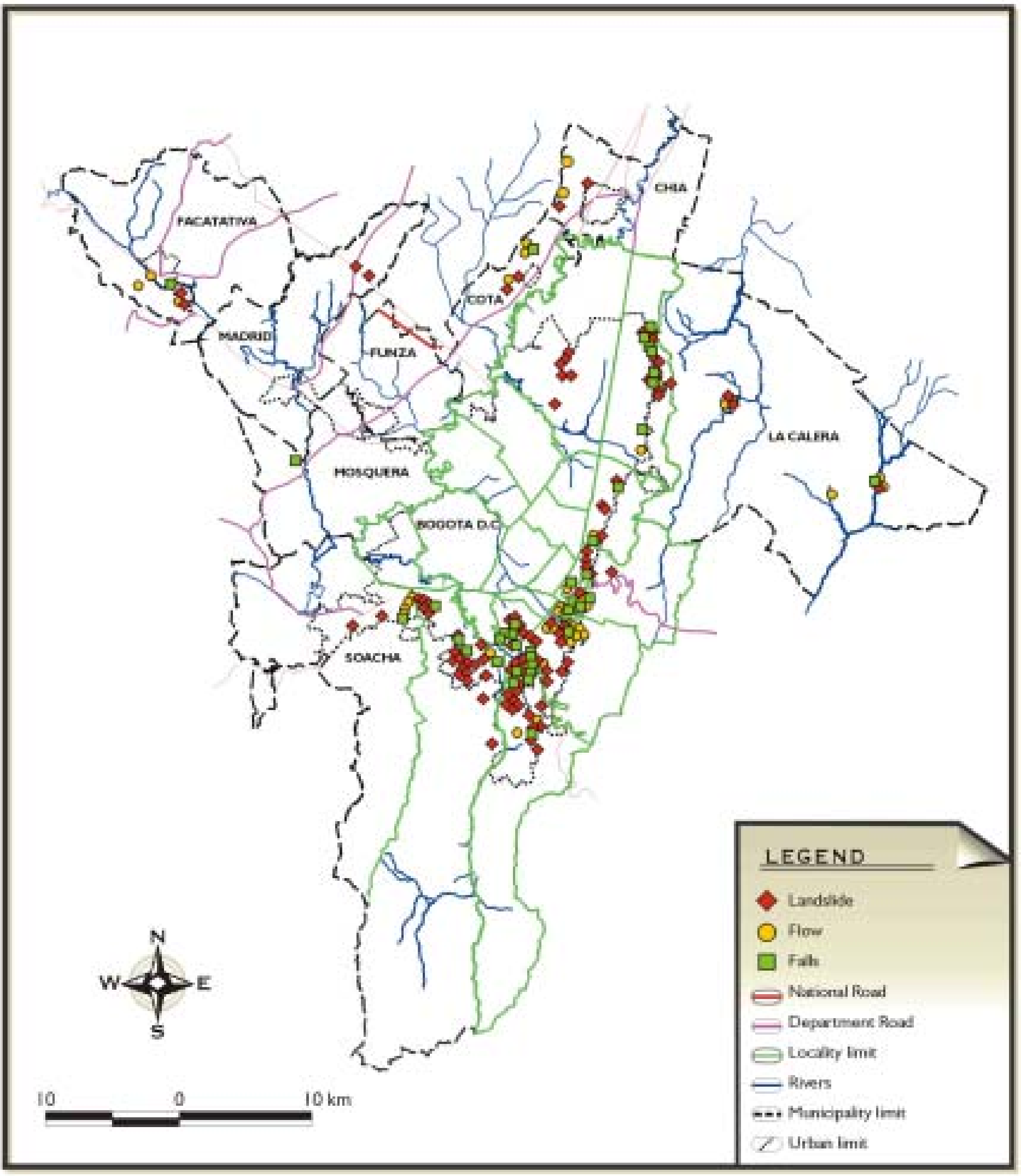
Grade 3 (Bb): Only non-structural measures would be required.

2) Results of Hazard Assessment

Figure 3.1.2 shows the distribution of hazardous slopes disaster identified in this study as classified by hazard types. Number of slopes classified by process for each municipality is shown in Table 3.1.5. Figure 3.1.3 shows the distribution of hazardous slopes as classified by risk levels. Number of hazardous slopes classified by risk for each municipality is shown in Table 3.1.6.

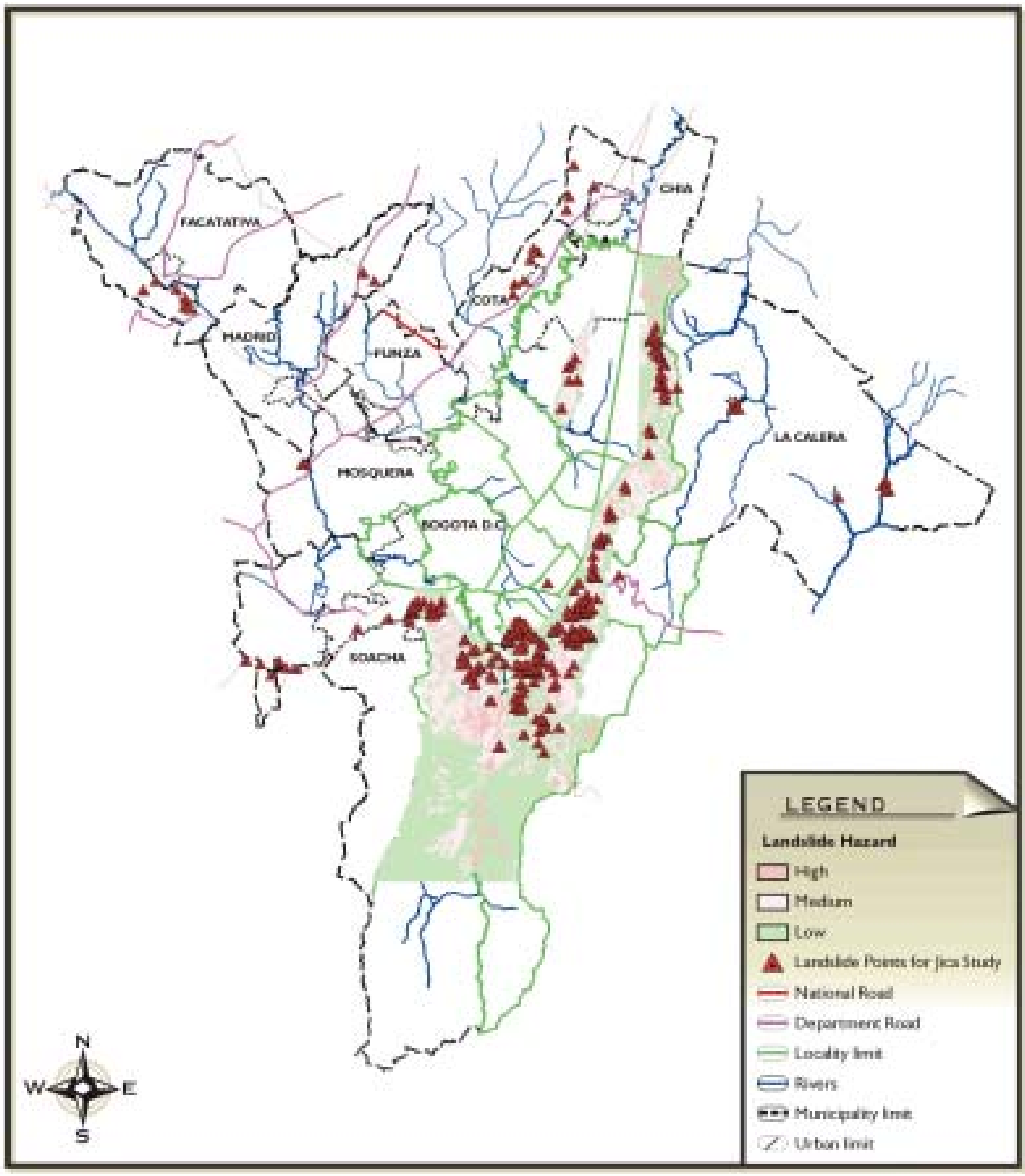
The result of this study shows that hazardous slopes are concentrated at where housing area is close to or on the slope, and located in the southern and southeastern part of Bogotá or in Soacha. In such places, houses are constructed near or on the slopes that are intrinsically hazardous. In this sense, many of these hazardous slopes are not necessarily to be called as natural hazard.

Some rock fall hazardous areas locate at the side slope along the main road. Rock fall would occur and at least one side lane would be impassable in a sever earthquake.



Source: JICA Study Team

Figure 3.1.2 Distribution of Hazardous Slopes Classified by Disaster Type



Source: JICA Study Team

Figure 3.1.3 Distribution of Hazardous Slopes Disaster as Classified by Risk

Table 3.1.5 Number of Slope Disaster as Classified by Process

	Process Type									
Municipality	Rotational landslide	Traslational landslide	Rock fall	Debris fall	Debris flow	Earth flow	Mud flow	Subsidence	Total	%
Bogota	236	47	56	6	1	21	5	0	372	87.9
Chia	2	0	0	0	1	1	0	0	4	0.9
Cota	0	0	3	0	0	3	0	0	6	1.4
Facatativa	2	0	1	0	1	2	0	1	7	1.7
Funza	0	0	0	0	0	0	0	0	0	0.0
La Calera	4	0	0	0	1	3	0	0	8	1.9
Madrid	0	0	2	0	0	0	0	0	2	0.5
Mosquera	0	0	2	0	1	0	0	0	3	0.7
Soacha	3	2	8	0	3	5	0	0	21	5.0
Total	247	49	72	6	8	35	5	1	423	100.0
%	58.4	11.6	17.0	1.4	1.9	8.3	1.2	0.2	100.0	

Source: JICA Study Team

Table 3.1.6 Number of Slope Disaster as Classified by Risk

	Risk				
Municipality	Grade1	Grade2	Grade3	Total	%
Bogota	77	50	245	372	87.9
Chia	0	1	3	4	0.9
Cota	2	2	2	6	1.4
Facatativa	2	3	2	7	1.7
Funza	0	0	0	0	0.0
La Calera	2	2	4	8	1.9
Madrid	1	0	1	2	0.5
Mosquera	2	1	0	3	0.7
Soacha	8	9	4	21	5.0
Total	94	68	261	423	100.0
%	22.2	16.1	61.7	100.0	

Source: JICA Study Team

3) Major Findings

In the Study Area, “earth flow”, a type of disaster in which surface soil or part of weathered base rock flows is remarkably recognized. Collapse of base rock at the wasted quarries is also prominent. These phenomena should be differentiated from “landslide” in narrow sense.

Such types of hazardous slopes distribute in gentle slope areas in wasted quarries and along the Blanco River in La Calera. Almost of those hazardous slopes disasters are classified as “earth flow”. The basic cause of such abundant earth flow are precipitation, deep weathering due to the slow emergence movement that allows slow erosion in periphery of Bogotá basin, and abundant organic surface soil whose thickness is from 1 to 2 m from Sabana formation.

In the western side of western end backbone from Soacha to Facatativa, erosion prevails over weathering so that the slopes with underdeveloped weathering are the majority. Therefore earth flow is limitedly seen in the re-movement of glacial deposit.

The types of slope disaster in the future are earth flows in steep slopes, rock fall at the foot or on the edge of wasted quarries and large scale landslide in the inhabited area. Hazardous locations in each municipality are described as follows:

(1) Bogotá

Landslide records and hazardous landslide areas are concentrated in slope areas that were developed without proper stabilization works due to the rapid expansion of housing area. In many cases, supply of piped water without installation of sewer pipes caused infiltration of wastewater and triggered earth flow together with rainfall.

(2) Chia

Small-scale landslides exist at the east slope of Majuy Mountain. However, the record of landslide is very limited. No slope and landslide exist in the urban area. Some slopes are unstable at the valley along the Frio River due to erosion.

(3) Cota

There are no slope or landslide areas in the urban zone. Hazardous landslide and rock fall areas are identified at the eastern side of the slope of Majuy Mountain, where operative or abandoned quarries exist. However, there is little landslide record.

(4) Facatativá

Earth flows exist at the both sides of the valley slopes near Sorrento, located in the east of the urban area. Heavy damages are anticipated in the densely populated northern slopes.

(5) Funza

There is no slope in the municipality.

(6) La Calera

Earth flows are widely recognized on slopes near El Manzano along the Blanco River. Landslides one in progress there due to the constant erosion at the foot of the slopes by river flows. Debris flows would occur if a landslide occurs there, river water is dammed up about 10 m, and the water head would remove finally blocking soil. On the other hand, ruins of the destructed bridges in the Blanco River indicate the several occurrences of debris flows.

In western side of the urban area, earth flow marks with about 5.0 m deep are observed on the slopes. Its movement is prominent in earth cut area.

In the western mountainous part of the municipality, a river with a relatively large river basin, flows into the urban area. Flooding were repeatedly happened in the parking area of apartment houses near the junction of flows.

(7) Madrid

There is no landslide in the urban area. But there are some rock fall areas which would cause traffic interference on the road that cross the Majuy Mountain in the northern part of the municipality in case of an earthquake.

(8) Mosquera

There is no slope in the urban area. But there are a few hazardous slope areas with rock fall at the southern part of the municipality, where residential buildings exist beneath the abandoned quarries.

(9) Soacha

Rock falls with 1.0 m in diameter are observed at the slope along the road from Soacha to Granada. Rock falls will possibly occur there in future due to its dip slope structure. One road lane would probably be blocked in case of a sever earthquake.

Similar conditions are also observed at the slope along the road (Soacha-Santandercito) at El Charquito.

In the southwestern part of the urban area, there is a high possibility of rock falls at the dense house buildings near the abandoned quarry at El Altico.

A large-scale landslide occurred in January 2000 at the right side slope of the downstream from the lake Terreros. The area is currently stable due to the counter embankment. However, it is possible to slide again due to the lack of a drainage system.

In Pavimentos Roka, there was a circular slide from the crest of the scarp at the abandoned quarry, and some houses had been damaged. The area is still in dangerous state because houses gather atop of the scarp.

3.1.3 Flood

1) Hydrological Aspects

(1) Rainfall

There are two rainy seasons such as April to June and October to November in this area. Annual rainfall depth varies from less than 500 mm to more than 1,500 mm.

Among many rainfall gauging stations, with the consideration of distribution and observation period, ten stations of EAAB were selected for analysis of rainfall characteristics (Locations, see Figure 3.1.4.). As for the analysis, one-day rainfall data for these stations were collected.

Figure 3.1.4 Location of Rainfall Station Analyzed

Maximum one-day rainfall among the analyzed station is recorded at San Luis and amount is 129.0 mm (Apr. 12, 2000).

According to the comparative study of large amount of rainfall day, it was found that there are few relationships of rainfall amount among these stations. Therefore, it is judged that a heavy rainfall usually restricted in the small area.

Table 3.1.7 Probable One-day Rainfall in the Study Area

Unit: mm

	5-year	10-year	50-year	100-year
Cerro de Suba	49	55	69	75
Fontibón	45	52	68	75
Bosa Barreno No.2	40	46	60	66
Usaquén-Santa Ana	65	75	99	109
San Luis	66	78	103	114
San Francisco-Salitre	67	78	100	110
Vitelma	56	64	82	90
El Delirio	56	63	78	84
Bocagrande-Salitre	49	55	69	75
San Rafael	56	64	82	90

Source: JICA Study Gumbel Method

Table 3.1.8 shows the relationship between duration and rainfall by probability.

Table 3.1.8 Relationship between Duration and Rainfall

Unit: mm

	Suba			Juan Amarillo		
	1 hour	3 hours	6 hours	1 hour	3 hours	6 hours
10-year	45.7	54.1	54.7	29	45	52
50-year	60.2	72.3	73.1	-	-	-
100-year	64.2	76.6	77.3	39	52	67

Source: EAAB, DPAE

Since the table was prepared as a result of combining of different data source, some discrepancies could be found out. Causes of these discrepancies could not be confirmed in this study, because the reports presented only the results of analysis and not presented and/or mentioned the original data and method of process.

The results of analysis show that the one-day rainfall amount is almost same amount of 6-hours rainfall. According to this result, it is supposed that duration of rainfall would be short and usually less than 6-hours.

(2) Run-off analysis

There are several water level gauges along the Rio Bogotá and the discharges of the river have been estimated using "water level - discharge curve." During the study in Colombia, efforts were made to obtain the water level records, but they all proved futile.

Several runoff analyses for the Rio Bogotá have been conducted. The latest study is *Estudios Hidraulicos Geotecnicos y Topograficos para Definir el Nivel de los Jarillones y Obras Requeridas para Mitigar el Riesgo de Inundacion del Rio Bogotá, en el Tramo Alicachin Humedal la Conejera*, which was conducted by EAAB. The runoff simulations in this study were carried out by using the same model as the one used in the previous study in 1985, with the following conditions:

Table 3.1.9 Summary of Conditions for Run-off Discharge Analysis (EAAB Study)

Item	Conditions
Rainfall Pattern	TORCA FUSAL
River Section	Conejera – Juan Amarillo Juan Amarillo – Fucha Fucha – Tunjuelo Tunjuelo – Arlcachin
Return Period	5-year 10-year 25-year 50-year 100-year
Rio Fucha Retention Pond	With retention pond Without retention pond

Source: EAAB Study

The simulation results of the EAAB study are shown in Table 3.1.10.

Table 3.1.10 Simulated Run-off Discharge of Rio Bogotá (EAAB Study)

	TORCA				FUSAL with Regulation pond				FUSAL without Regulation pond			
Return Period	5	10	50	100	5	10	50	100	5	10	50	100
Conejera – Juan Amarillo	62	70	90	99	43	49	62	67	45	51	64	69
Juan Amarillo – Fucha	83	97	133	148	71	83	114	128	76	91	122	136
Fucha – Tunjuelo	110	123	160	175	121	135	173	189	171	189	227	243
Tunjuelo – Alicachin	140	152	186	201	166	193	259	287	190	220	287	315

Source: EAAB Study

The runoffs of the three tributaries were calculated as a part of the flood risk zoning study conducted by DPAE; however, there was no information on runoff of the tributaries in the western side of the Rio Bogotá because the hydrological study has not been conducted on the western side of the river.

All the studies for the three tributaries have applied HEC for calculation of flood runoff, and it can be judged that the analysis was conducted appropriately by reviewing the study report.

Figure 3.1.5 shows the flood run-off discharge distribution of the Rio Bogotá system in the Study Area. The figure was prepared by combining the several information obtained from the reports prepared by EAAB and DPAE, because there are no hydrological and discharge analysis which is targeted to the whole river system of the Rio Bogotá.

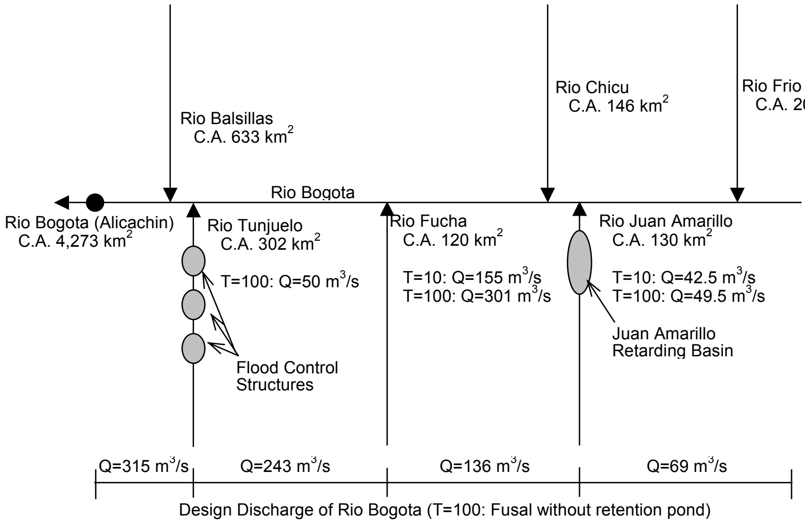


Figure 3.1.5 Flood Run-off Discharge Distribution (Rio Bogotá System)

2) Flood Damage

(1) General

In order to estimate the flood damage, it is necessary to carry out the flood condition survey (depth, duration, frequency, etc) and assets survey (value of house/commercial building, assets value per household/commercial by position from the floor, etc.). However, since these kinds of survey works were not included in this study, it is impossible to estimate the flood damage in the monetary term. Thus, the flood damage of the Study Area will be shown using the number of population/household, the area of inundation by flood frequency. These calculations have been done using the GIS database prepared by this Study.

(2) Areas affected by inundation

Affected areas by risk zone are shown in the Table 3.1.11. Total inundation area of 6,760 ha represents 18 % of urban area of Bogotá City of 37,964 ha, which is based on JICA Study Team's database.

Table 3.1.11 Areas Affected by Inundation (Bogotá City)

	Inundated Area (ha)
High Risk Zone	2,300
Medium Risk Zone	3,500
Low Risk Zone	960
Total	**6,760**

Source: JICA Study

Affected areas of inundation by municipalities in Cundinamarca are shown in Table 3.1.12. The areas calculated using the inundation map provided by the municipalities. Since the maps have no classification of risk zone, only total affected area could be calculated.

Table 3.1.12 Areas Affected by Inundation (Municipalities in Cundinamarca)

Name of the Municipalities	Inundated Area (ha)	Ratio of Affected Area (%)
Chia	520	6.5
Cota	920	17.2
Facatativa	210	1.3
Funza*[1]	80	1.1
La Calera	1,320	4.2
Madrid	-	-
Mosquera*[1]	20	0.2
Soacha	980 *[2]	5.3

Source: JICA Study

*[1]: Municipalities that do not have their own POT data for Flooding. Data obtained from flood risk of neighboring Municipality

*[2]: Figures for Soacha City includes the affected area of dam failure of terreros dam.

(3) Population and households affected by inundation

Affected population and households by risk zone are summarized in the table below.

Table 3.1.13 Affected Households and Population by Inundation (Bogotá City)

	Affected Household	Affected Population
High Risk Zone	16,200	84,400
Medium Risk Zone	46,900	284,100
Low Risk Zone	20,800	128,300
Total	**83,900**	**496,800**

Source: JICA Study

Affected numbers of populations and households by inundation by City in Cundinamarca are shown in Table 3.1.14.

Table 3.1.14 Affected Households and Population by Inundation (Municipalities in Cundinamarca)

Name of the City	Affected Household	Affected Population	Ratio of Affected Population
Chia	860	3,140	4.8
Cota	410	1,610	10.7
Facatativa	2,450	16,520	18.3
Funza	10	40	0.1
La Calera	120	440	1.9
Madrid	-	-	-
Mosquela	5	20	0.0
Soacha	12,160 *	96,660 *	17.6

Source: JICA Study

*: Figures for Soacha Municipality includes the affected area of dam failure of terreros dam.

3) Existing Flood Risk Map

(1) Bogotá City

A. Existing flood risk map

The existing flood risk map was prepared by DPAE in 2000 based on the Flood Risk Zoning Studies, which were conducted from 1999 to 2000 for all possible inundation areas of Bogotá City.

The studies have included risk analysis, which has been carried out based on the analysis of hazard, vulnerability and prevention. However, the prepared flood risks map for the POT Bogotá only shows the flood hazard areas by the probable floods of 100-year and 10-year return periods under the current land use and river conditions.

According to the flood risk map, the areas along the Rio Bogotá, the Rio Tunjuelo and the Rio Juan Amarillo are identified as the flood risk areas.

B. Evaluation of existing flood risk map

Based on the results of review of flood risk zoning studies and the topography, and the observations of field investigation, it is possible that the map shows the flood hazard areas.

(2) Other municipalities

A. Existing flood risk map

Some municipalities have included flood (or inundation) hazard maps in their POT, which are prepared based on the flood records in the past; however, no hydrological/hydraulic conditions have been studied based on them. The possible flood areas in the past would be assessed from hydrological and hydraulic aspects.

B. Evaluation of existing flood risk map

The existing flood risk maps have been prepared based on the past flood records, but no hydrological/hydraulic assessment has been conducted. Accordingly, the existing flood risk maps only show the past flood (or inundation) areas; an assessment would be necessary in future.

3.1.4 Industrial Facilities

1) Bogotá city

- The directed management towards the prevention and control of the technological risk is not known in the micro and small companies, including the concepts of basic risk prevention activities that have to be sponsored by the professional risks administrators–the ARP.
- The micro and small companies have difficulties in responding to the environmental management and the industrial safety-related subjects, because they do not have the appropriate personnel and knowledge.
- There exists a conceptual and technical disregard referent to the technological risk prevention as well as the seismic threat. Many companies do not have an adequate methodology of danger identification and risk evaluation, that would facilitate the prioritising of the prevention and control measures, and would allow to estimate the possible consequences in case of a dangerous accident. This situation implies that the internal as well as external respond-to-emergency entities are ineffective in the control of such accidents despite the generalized schemes outlined in the current respond-to-emergencies plans.
- The preparation and response to emergency plans do not include preventive strategies and the environmental impact minimization, during and after a serious accident.
- Other faulty aspects as to its administration are the ones related to the information and managing of the preventive operations as well as the chemical substances in the companies, because the minority got acceptable score in these aspects, generally coinciding with bigger international companies. However, even these international companies do not have enough countermeasures to the seismic threats.

2) Eight Municipalities

In order to find out the vulnerability of the eight municipalities, the gathered information was analyzed in terms of preparedness level to handle an emergency, preparedness for earthquake and community risk.

(1) Preparedness level to handle an emergency

The preparedness level of municipalities to handle an emergency is shown in Table 3.1.15 and a brief description follows.

Table 3.1.15 Preparedness Level to Handle an Emergency in Eight Municipalities

Municipality	Good (%)	Regular (%)	Poor (%)
Chía	0	13	87
Cota	3	31	66
Facativá	4	41	55
Funza	0	26	74
La Calera	0	14	86
Madrid	4	38	58
Mosquera	7	60	33
Soacha	7	18	75

Source: Study on the Prevention of Industrial Disasters in the Bogotá Metropolitan Area (2001) by CCS “

- Chía: In general, most enterprises were equipped for fire-fighting but lack equipment and plans to control leaks and spills, and 100% were “deficient” or “poor” for level of preparedness for emergencies, “poor” being the larger group.
- Cota: In general, the companies have resources to handle fires but they lack appropriate elements and plans to control spills or leaks. Their emergency preparedness level falls under deficient or poor at 97% with the former being more predominant 66%.
- Facatativa: In general, companies have resources to attend to fires, but lack appropriate elements and plans to control spills or leaks, and the preparation level for emergencies is in 96% of the cases between deficient and bad.
- Funza: In general, the enterprises have fire-fighting equipment, but they lack equipment and plans to deal properly with spills or leaks and the level of preparedness for emergencies is 100% deficient or poor, with “poor” having the greater edge 64%.
- La Calera: In general, the companies have resources to handle fires but lack the appropriate elements and plans to control spills or fires and the emergency preparedness level is 100% between deficient and poor, with the latter having the greater share.
- Madrid: In general, the companies have resources to handle fires but have inappropriate elements and plans to control spills or leaks, and 96% of the evaluated sample has an emergency preparedness level between deficient and poor, with the latter prevailing 58%. Four percent has a satisfactory level in this aspect.
- Soacha: The events of greatest importance are fire followed by spills. In general, most enterprises are equipped to fight fires, but lack proper plans and equipment for spills or leaks.

(2) Preparedness for earthquake

Preparedness for earthquake is shown in Table 3.1.16.

The results are not so reliable since most of the survey respondents had no knowledge of the subject matter, and no other sources of information were available. However, it is clear that there is no regulation for anti-seismic design for the industrial facilities and even the bigger international companies do not pay attention to the seismic threats.

Table 3.1.16 Preparedness for Earthquake

Municipality	None (%)	Deficient (%)	Acceptable (%)
Chía	74	20	6
Cota	31	48	21
Facatativa	38	48	14
Funza	47	29	24
La Calera	86	14	0
Madrid	51	33	16
Mosquera	27	73	0
Soacha	62	36	2

Source: Study on the Prevention of Industrial Disasters in the Bogotá Metropolitan Area (2001) by CCS

(3) Community risk

Evaluation and cross analysis of variables, type of threat, preparation level for attention of emergencies and distance to the community are made and the results are shown in Table 3.1.17.

Table 3.1.17 Analysis Results to the Community Risk

Municipality	High Risk Company		Medium Risk Company	
	Number	(%)	Number	(%)
Chía	1	2	41	89
Cota	0	0	11	38
Facatativa	7	24	15	52
Funza	10	13	48	63
La Calera	1	7	13	93
Madrid	16	36	20	44
Mosquera	3	20	6	40
Soacha	18	15	79	67

Source: Study on the Prevention of Industrial Disasters in the Bogotá Metropolitan Area (2001) by CCS

- Chía: Only one food producer represents a high risk to the community due to the quantities and nature of the substances it handles, the low level of preparedness for emergencies, and its physical closeness to the community.
- Cota: Six companies represent a major threat for the community, due to the quantity and nature of the substances they handle. But, differently from other municipalities, in Cota there were no systems identified as representing high level of risk for the community, basically because the community is far from the industrial establishments.
- Facatativa: Twelve 12 companies represent a major threat for the community due to the quantities and nature of the substances that they work with. However, only 7 of these enterprises have a high-risk level for the community due to their deficient preparation for emergencies and their proximity to the community. This group includes, as mentioned

before, wholesale commerce of LPG and other systems four of the industrial sector, one of the commercial sector of gasoline service station.

- Funza: Twelve companies are a major risk to the community due to the quantities and nature of the substances handled; most then are high community risk, given the lack of preparedness for emergencies and their closeness to the community. This group includes retail LPG and other industrial compressed gas outlets. Thus, the substances which appear most often as a major threat are LPG and acetylene, also related to the fact that leaks and explosion have a higher preponderance than spill in the rating of events.
- La Calera: Just the service station represents a major threat for the community due to the amount of gasoline stored therein. However, there were no serious accidents involving them (even in time of earthquake in Japan), because gasoline is stored in the underground tank. The remaining companies are classified as minor threat and offer a medium level of risk for the community.
- Madrid: Twenty-one companies represent a major threat to the community due to the amount and nature of the substances they handle. 36 percent of them represent a high level of risk for the community due to deficient emergency preparedness and closeness to the community.
- Mosquera: Seven companies represent a major threat for the community due to the amount and nature of the substances they handle, but less than half display a high level of risk for the community since the others are far from the community.
- Soacha: There are 18 enterprises in the Soacha sample which show high community risk, since the volume and character of the substances handled mean that the risk of accidents might be high. According to the replies to the surveys, these enterprises are not prepared or badly prepared to react to possible accidents identified; they do not have any proper system to mitigate earthquake damage, or have none at all. And in an emergency, the community might suffer serious harm since it is close to the premises of those enterprises.

3) Transportation System of Hazardous Materials

There are a lot of emergencies with chemical substances enroute their transportation through different highways connecting cities across the country and going through municipalities as mentioned before. It is important to note the fact that at the moment there are no regulations in Colombia that control the transportation of this kind of materials, causing situations like the ones given below:

- Transportation in vehicles that do not meet safety standard regarding the design of the vehicle nor the transporting unit (container).
- The driver lacks minimum knowledge of the dangers of the chemical product being transported.

- Several chemical substances are transported in one vehicle, ignoring incompatibility among the materials.
- The response mechanisms to emergencies, when they occur, are limited and in most cases, transporters fail to react.
- For some transportation companies, the interest is usually limited to the immediate delivery of the material, ignoring many times the dangerousness of the chemical substances on board.
- Most of the vehicles are not marked with labels as established in the Norm ICONTEC NTC 1692 (based on the International Classification System of the United Nations), which is mandatory. This norm establishes the use of labels that identify the dangerousness of the substance being transported, as Inflammable Liquid, Corrosive, Inflammable Gas, etc.

3.2 Vulnerability Analysis

3.2.1 Physical Vulnerability

1) Buildings

(1) Building regulations for earthquake resistant design and construction

A. Historical review of Colombian seismic regulations

Establishment of Colombian seismic regulation is surveyed by the Study Team and summarized as listed in the following table:

Table 3.2.1 Historical Review of Building Regulation in Colombia

Year	No. of Law or Decree	
		--- Before 1984, No regulation for earthquake resistant design and construction
1983	National Law 11	Announcement of the first law for earthquake resistant design and construction (Due to Popayán earthquake (March 31, 1983))
1984	National Decree 1400	Issue of the first regulation for earthquake resistant design Almost dead copies regulations of the United States' regulations (The related decrees of Law 11, 1983)
1995	City Agreement 20	Introduction of micro-zoning* (Due to enforcement of National Law)
1997	National Law 400	Establishment of own regulations of Colombia (According to recommendation of IAEE**)
1998	National Decree 33	Covering almost all the items in relation to building design and construction (Progress of work by AIS)
1999	National Decree 34	Modification of Decree 33 (Progress of work by AIS)
2000	National Decree 2809	Repair, Reinforcement and Rehabilitations of Buildings (Due to lack of regulations)
2001	City Decree 74	Renewal of micro-zoning identification

* For Bogotá City Only
** IAEE: International Association of Earthquake Engineering
*** AIS: Colombian Earthquake Engineering Association

a) Law 11 of 1983 and decree 1400 of 1984

It is to be noted that the building regulation in the Republic of Colombia was, for the first time, established in 1984 after the Popayán earthquake in 1983.The earthquake occurred in March 31 at 10-kilometer depth in the Southwestern region of Colombia with magnitude 5.5 causing 241 deaths and 1,500 injured in the city of Popayán and surrounding local towns. Until that time, all the buildings in the Republic of Colombia were designed and constructed without any legal constraint with respect to seismic resistant capability, even if the building was too high to properly resist an earthquake force. Only experienced structural engineers used the United States' building code (UBC: Uniform Building Code) as a general guide for design and construction code and

SEAOC code (SEAOC: Structural Engineers Association of California) as a guide for an earthquake resistant design code.

In the end of 1983, Law for Earthquake Resistant Construction (Ley 11 de 1983) was announced and the related Decree was issued (*Decreto 1400 de 1984:Codigo Colombiano de Construcciones Sismo-Resistentes*).After 1984, related building regulations such as construction enforcement law were issued accordingly.

b) NSR 98

As the aforementioned regulations were are almost dead copies regulations of the United States' regulations, and as the International Association of Earthquake Engineers (IAEE) strongly recommended the member countries to establish their own regulations, the members of the Colombian Earthquake Engineers Association (AIS) headed by Professor Sarria info the Los Andes University had made an effort to revise and update the regulation since around 1993.Then, in 1997, the national law for the earthquake resistant design and construction for the buildings was issued, which was followed by several decrees issued in 1998, 1999 and 2000, respectively. The latest decree states the Repair, Reinforcement and Rehabilitation of buildings. These sequential law and decrees have been compiled into two volumes of publication as NSR-98 (*Normas Colombianas de Diseno y Construccion Sismo Resistente*: Colombian Regulations for Earthquake Resistant Design and Construction) by the Colombian Earthquake Engineering Association (AIS). NSR-978 is composed of Ley (Law) 400 de 1997, and these were followed by Decreto (Decree) 33 de 1998, Decreto 34 de 1999 and Decreto 2809 de 2000, respectively.

Among these law and decrees, Decreto 33 is the most important and covers almost all the items in relation to building design and construction, which is composed of the found in the following chapters: as;

- General requisitions for earthquake resistant design and construction (124).
- Loadings (42).
- Concrete structure (228).
- Masonry structure (68).
- Housing with 1-2 story (18).
- Metallic structure (380).
- Wooden building (60).
- Geo-technical studies (56).
- Technical supervision (14).
- Requisitions for fire protection of building (12).
- Complementary requisitions such as wind load (34).

* Number in ( ) is page amount.

c) Microzoning study

Under the framework of these national laws and decrees, it is recommended that the big cities with more than 100,000 populations in Colombia are recommended to issue their own decree for the design and construction practices based on the microzoning studies. Therefore, the city of Bogotá issued several decrees under the name of the mayor.

For instance, in 1995, Construction code for the city of Bogotá was issued as Agreement of 1995 (Acuerdo 20 de 1995). The latest mayor's decree was issued on January 30, 2001 as Decree of 74 (Decreto 074) by which the Construction code for the city of Bogotá was partly modified and seismic microzoning was newly identified. Referring to the decree, the city of Bogotá is divided into 10 micro zones, i.e., 1A, 1B, 2A, 2B, 2C, 3A, 3B, 4, 5A and 5B.Design spectrum is also identified in the decree for the application to Bogotá City.

B. Status of present regulations

Status of Colombian building regulation and its organization are illustrated as shown in the following Figure 3.2.1.

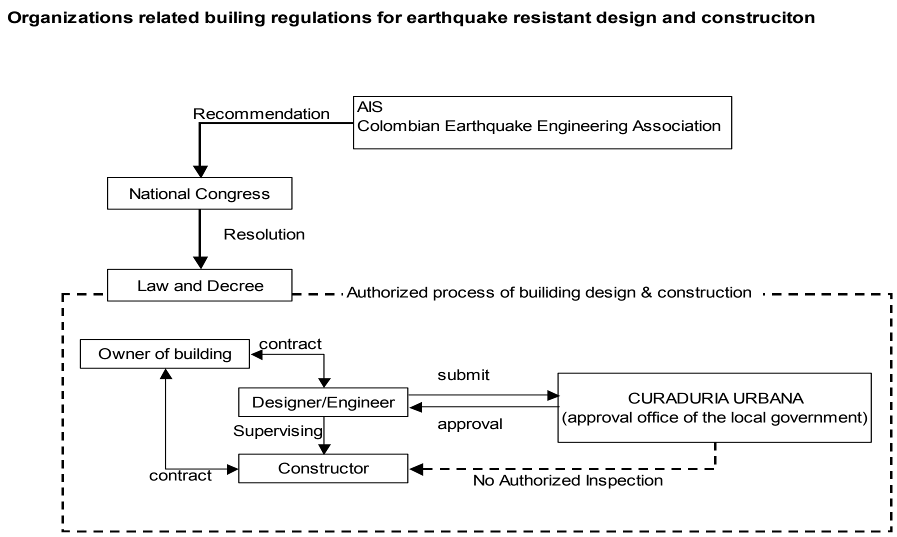


Figure 3.2.1 Status of Building Regulation and Organization

It is found throughout the brief review of the aforementioned laws and decrees by the Study Team, that the regulatory guides for the earthquake resistant design and construction in Colombia and in the city of Bogotá is, to some extent, satisfactorily prepared. The items and contents of the regulation cover almost all the factors that are now taken into consideration in the USA as well as in Japan. For example, the concept of Soil-Structure Interaction is formulated in the decree, which necessitates highly sophisticated knowledge and experiences of the designers/engineers.

C. Discussions of on building regulations

a) Masonry structure

The description for the masonry structure should be increased and reconsidered with much more careful attentions. For example, the minimum thickness of masonry wall (approx.100mm), defined in the decree, should be reconsidered, because, with the thickness of 100 mm of brick, seismic resistance of masonry structures is not guaranteed due to the rather rigid stiffness and consequent bigger earthquake forces. In Japan, non-reinforced masonry is prohibited and minimum thickness of masonry wall is 15 cm for a one- story housing unit.

b) Inspection process

Regarding the inspection during and after the construction work, moreover, it is said that there is no legislated and/or authorized process. Although before the construction of the building, the designers/engineers in Colombia have to submit all the building documents to the CURADURIA URBANA (approval office of the local government) in order to get the construction approval, the consequent inspection by authorized institutions during and after construction is not mandatory. In the USA as well as in Japan, the inspection of the construction site by the authorized institution is mandatory in order to guarantee the quality of the building constructed. Therefore, establishment of the inspection process as well as the full enforcement of the decree should be of the most urgent matter.

c) Provision for informal building

It is also regrettable that the unskilled laborers, who lack the sense of law abiding, have been constructing many informal buildings during long periods even after 1984.It is attributed to shortage of systematic process to stop to build informal buildings this practice because of the lack of related regulations and enforcement of law and so forth. The informal buildings are mostly lack the resistance to the earthquake forces and cause the tremendous damages to the residents as well as the properties when earthquakes attack.

d) Provision for retrofitting

Seismic retrofitting is also of the other urgent matter. From the practical viewpoint, the regulation above gives, although necessary items for the retrofitting design are described in the regulations mentioned above, no practical methods to be applied to the retrofitting works for the existing building are given. As Japanese building engineers, based on accumulated earthquake experiences and consequent researches and developments, have sufficient technologies and knowledge on this matter, it is possible to transfer these necessary techniques as well as preferable materials to the Republic of Colombia.

(2) Vulnerability of existing important/essential buildings

A. Diagnostic investigation of existing important/essential buildings by the study team

a) Objectives of diagnostic investigation

The Study Team investigated several existing important/essential buildings in the City of Bogotá and in the eight municipalities with its counterpart, of DPAE. The objectives of the investigation are 1) to check the present condition of the existing important/essential public buildings and 2) to clarify the seismic performance of the buildings, because these buildings are supposed to play important roles at the time of earthquake.

b) Method of investigation

Perfect diagnosis on the seismic performance of existing buildings can be done by the combination of many experimental and computational findings and by the professional experiences and judgments as shown in the following Figure 3.2.2.

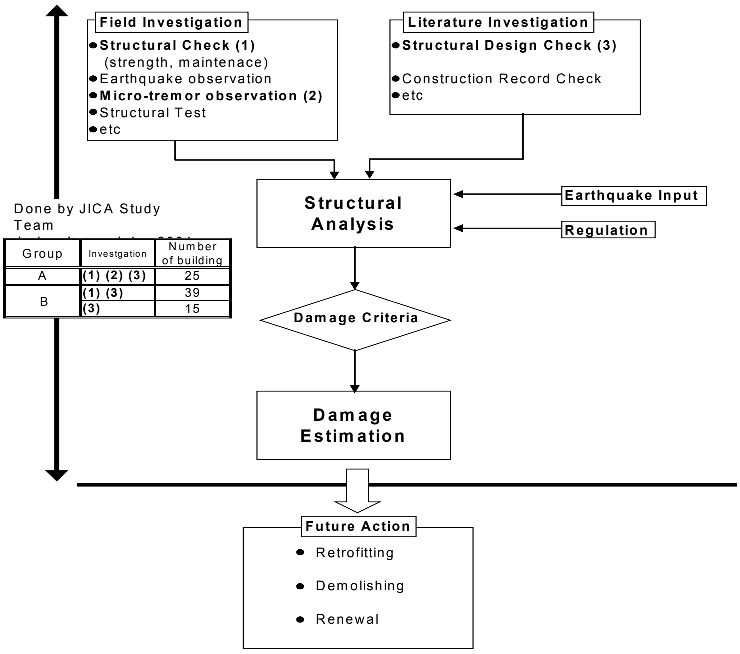


Figure 3.2.2 Flow Chart of Diagnosis of Existing Buildings and Scope of the StudyTeam

During the present phase of this study, site investigation with micro-tremor and structural design check were implemented by two groups (Group A and Group B) as shown in the figure. Group A visited 25 buildings while Group B visited and studied 54 in total. (Refer to Technical Report).

c) Micro-tremor measurement

The objective of micro-tremor measurement is to obtain the predominant period of the building. Predominant period is closely related to the vibration of the building not only in normal time but also in the event of an earthquake. The predominant period is determined by peak period of the power spectrum obtained and processed after micro-tremor measurement.

B. Results of diagnostic investigation of existing buildings

Diagnostic investigation was implemented from mid May to the beginning of June 2001.The results of the investigation on a total of 79 buildings are summarized in the following Table 3.2.2.

Table 3.2.2 Summary of Diagnostic Investigation by JICA Team

	Type	Location		Diagnosis				Sum
		Bogotá	Cundinamarca	Minor damage	Middle damage	Severe damage	Unknown	
Group A (Micro-tremor)	Housing	1				1		1
	Transport	1		1				1
	Government	7	3	2	2	6		10
	Medical	4	1		1	4		5
	Police	2			1	1		2
	School	4	2	1	1	3	1	6
	Sub-total	**19**	**6**	**4**	**5**	**15**	**1**	**25**
Group B	Church		2			2		2
	Commercial	2		1		1		2
	Transport	9				9		9
	Government	14	4	3	7	8		18
	Medical	8	1	1		8		9
	Police	5			1	4		5
	School	3	5	1	1	6		8
	Military	1			1			1
	Sub-total	**42**	**12**	**6**	**10**	**38**	**0**	**54**
TOTAL	Housing	1				1		1
	Church		2			2		2
	Commercial	2		1		1		2
	Transport	10		1		9		10
	Medical	21	7	5	9	14		28
	Government	12	2	1	1	12		14
	Police	7			2	5		7
	School	7	7	2	2	9	1	14
	Military	1			1			1
	Total	**61**	**18**	**10**	**15**	**53**	**1**	**79**

Source: JICA Study Team

C. Evaluations and findings of the results of investigation

From these investigations, several findings with respect to the vulnerability of existing buildings were obtained. Almost all the buildings visited and studied in this report were designed and constructed before 1984.Therefore, it was found that structures of these building did not have sufficient resistance or ductility against horizontal forces, which would cause serious damages when a moderate earthquake with a Peak Ground Acceleration (PGA) larger than 0.1g hit the building in future. Other findings are described as below:

- Masonry structure is in general categorized into three structures. One is non-reinforced masonry where masonry materials such as adobe, stone and brick are piled up with mortar and/or mud but without any reinforcing steel bars. The others are confined frame masonry where reinforced concrete frame composed of columns and/or beams are used together with masonry wall material, and reinforced wall masonry where masonry bricks are connected to each other by reinforcing steel bars. Because of high price of reinforcing steel bars and difficulty of getting these reinforcing bars at the time of construction, it seems that many of the old masonry buildings are of non-reinforced masonry structures and very vulnerable to even the small horizontal forces induced by earthquakes with a PGA less than 0.1g.
- Many buildings made of concrete structures are, as far as in this study scope, composed of relatively small sized columns in comparison with Japanese practice. Size of reinforcing steel bars are also very small in comparison with Japanese practice. For instance, one building has columns with only 0.3 x 0.3 square meter cross section area for a 7- meters span length. Concrete strength seems also seems very low because of the deterioration as well as due to the lack of quality assurance at the time of construction.
- Most of the concrete structures do not have beam but have waffle or joist slab. Slab thickness is between 15 centimeters and 40 centimeters, which cause the loss of structural integrity when subjected to horizontal forces. Because rigid connection of columns by using reinforcing steel bars to horizontal elements such as slab and joist is generally very difficult due to the small size of columns. As a result, the punching shear failure at slab portion is expected at the time of an earthquake.
- Moreover, it seems common that brick or concrete is used for the interior partition wall and/or façade wall as non- structural elements, which cause the heavy fixed weight of the building. Even more, as these non-structural elements are attached to structural columns, the bending capability of columns would be lost resulting in the shear failure of columns at the time of an earthquake. Lack of the transverse reinforcing steel bars would accelerate the shear failure and collapse of columns.
- Measured vibration periods of 25 buildings are shown in the Figure 3.2.3 below.

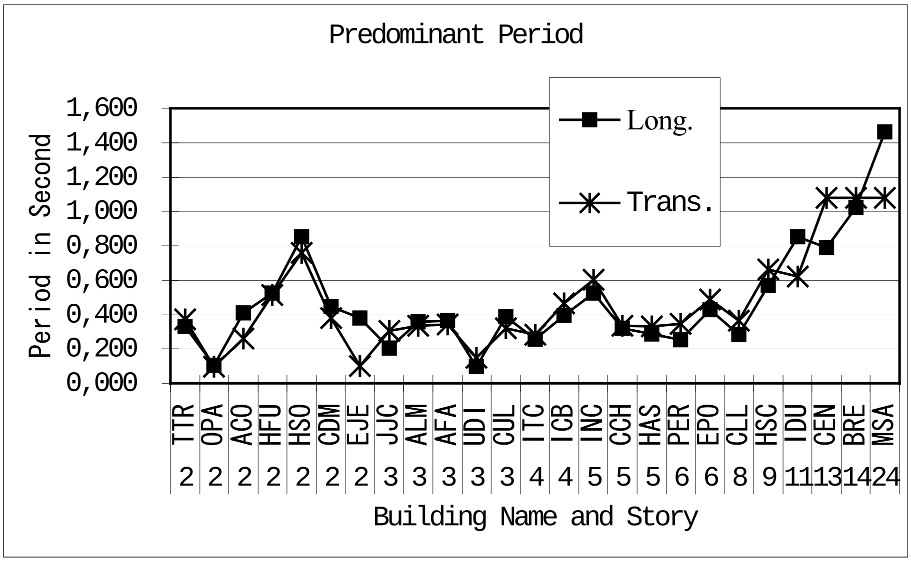


Figure 3.2.3 Predominant Period

From this figure, it is pointed out that 1) There are no general tendencies of the predominant periods of low-rise buildings, lower than 10 stories and that 2) However, predominant periods of high-rise buildings, higher than 10 stories, are proportional to the number of story.

- The aforementioned measured periods of low-rise buildings are largely attributed to the local soil conditions while those of high-rise buildings are due to their own structural characteristics. Because the soil's vibration characteristics are not filtered by the low-rise structures due to the short length of the structural height.
- Except for very few buildings, almost all buildings described in this report need, to some extent, retrofitting works considering the importance of the functions, seriousness of future damage due to the scales and number of users of each building. Retrofitting must be done urgently not only for structural elements but also for non-structural elements as well as mechanical equipments.
- The biggest problem in relation to construction quality is non-engineered structure mainly witnessed in the lower classed district Estrato bajo which makes the structural categorization difficult.

(3) Existing building's vulnerabilities

A. Building damages in Quindío earthquake

In the Quindío earthquake on January 25, 1999, the report by Los Andes University on building damages stated that " It was proven how dangerous it is for a city to count on an inventory of fragile buildings made of brick un-reinforced masonry and on of reinforced concrete structures with in adequate dimensions and steel reinforcement, that do not comply with the minimum earthquake resistant standards" and that " the benefits of designing and constructing structures using earthquake resistant standards, in accordance with the current art and knowledge, were proven, signifying not only the protection of life, but also of the citizen's patrimony."

Moreover, the University of Quindío and INGEOMINAS also published the damage report where the relation between building damages and earthquake intensity is represented as shown in Figure 3.2.4.

By using these relations, the building vulnerability in the city of Armenia at the time of Quindío earthquake is obtained in the form of damage function or fragility curve by the Study Team as shown in the following Figure 3.2.5.

VULNERABILITY	A			B			C			D			E			F		
DESCRIPTION	Constructions in diverse materials without mortar			Constructions in diverse materials with mortar			Structures in reinforced concrete without SRD			Constructions with reinforced concrete and several levels of seismic resistant designs								
KIND OF CONSTRUCTION	Adobe, bahareque, tapia pisada and others			Non reinforced masonry, blocks of stone			Reinforced masonry, with concrete plates			Confined masonry, RD with a minimum level of SRD, metallic structures and wooden constructions			Reinforced concrete (RC) with moderate level of SRD			Reinforced concrete (RC) with a high level of seismic resistant design		
PERCENTAGE (%) / DAMAGE	0-10	10-50	50-100	0-10	10-50	50-100	0-10	10-50	50-100	0-10	10-50	50-100	0-10	10-50	50-100	0-10	10-50	50-100
1. LIGHT. Small on few walls. Fall of stucco. Fissures at the adage between the structure and dividing wells	V	VI	VI	VI														
2. MODERATE. Small fissures con many walls. Fissures on columns and girders. Fall of stucco.	VI	VI	VI	VI	VII	VII	VII	VIII	VIII	VIII	IX	IX	XI	X	X	X	XI	
3. SERIUS. Wilde and widespread fissures on many walls. Fall of tiles. Detachment of concrete places. Fissures on girders	VI	VII	VII	VII	VIII	VIII	VIII	IX	IX	IX	X	X	X	XI	XI	XI		
4. SEVERE. Serious damages on walls. Partial damage of the structure. Damages on columns nodes. Deviation on columns. The reinforce is exposed.	VII	VIII	VIII	VIII	IX	IX	IX	X	XI	X	XI	XI	XI					
5. DESTRUCTION. Almost total collapse of the structure.	VII	IX	X	IX	X	XI	X	XI	XI	XI								

RD: Reinforced Concrete
SRD: Seismic Resistant Design
EXPLANATORY NOTE: Each intensity and its representative colors results from the combination of the damage percentage and the neighborhood vulnerability

Figure 3.2.4 Relation between Building Damage & Earthquake Ground Intensity in Armenia City

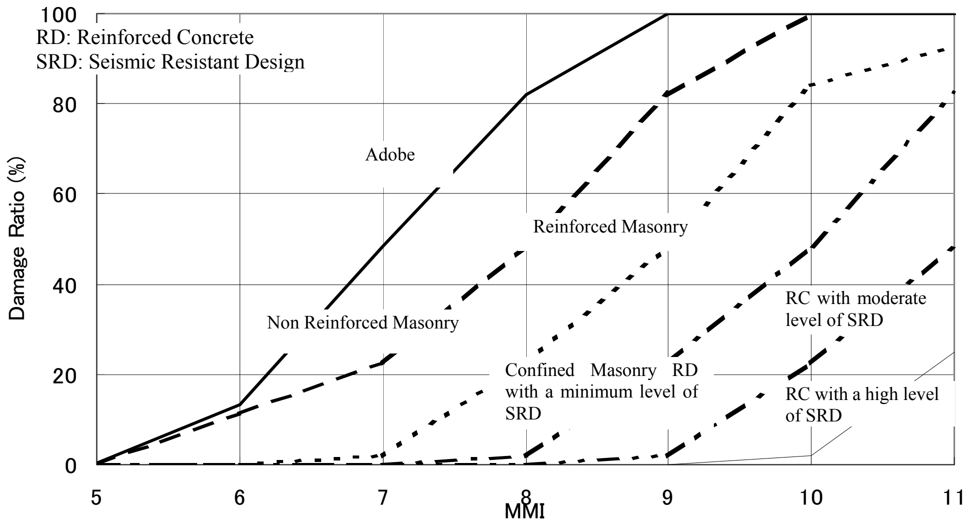


Figure 3.2.5 Damage Functions of Building Types in the 1999 Quindio Earthquake

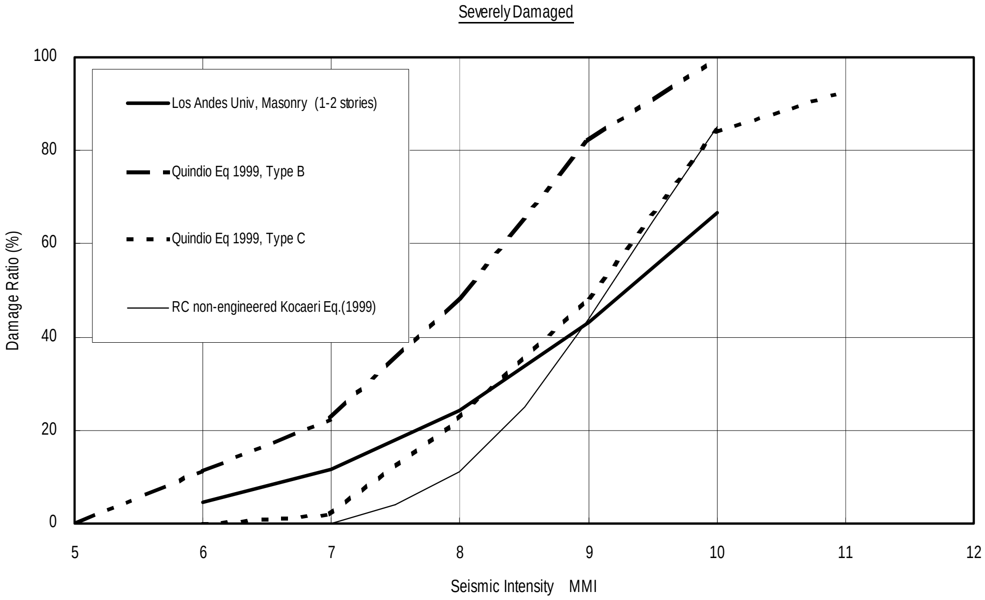
B. Comparison of damage functions

As described before, INGEOMINAS and the Los Andes University conducted the Microzoning Study from 1993 to 1997. In their study for of damage estimation of the buildings, the damage function was assumed and adopted in accordance with the definition by the Applied Technology Council (ATC) and the buildings' vulnerability was categorized into 7 types mainly for residential units. Their damage function for the masonry structure is compared with those obtained from the Quindío Earthquake and also. The damage function obtained at from the Turkey Earthquake [3-2-1] . They are shown in Figure 3.2.6.

In this figure, the earthquake intensity is expressed by Modified Mercalli Intensity (MMI) scale. If the earthquake intensity is expressed by Peak Ground Acceleration (PGA) instead of MMI, the relation between MMI and PGA described below is mostly used where G is gravity acceleration (9.8 meter/square second):

Log (PGA) = 0.3 MMI + 0.04

[3-2-1] (Kocaeri, August 17,1999).



(A: Adobe, B: Non Reinforced Masonry, C: Reinforced Masonry Others: Concrete)

Figure 3.2.6 Comparison of Damage Functions for Masonry Structures

2) Infrastructure

Information on vulnerability of infrastructures is very important for the preparation of a disaster prevention and mitigation plan. In this section, vulnerability analysis of infrastructures is described.

(1) Road facility

Following problems and issues have been identified from the point of view of physical vulnerability about the road facility.

A. Incomplete principal road network

a) Bogotá city

The principal road network in Bogotá City is generally formed by ring and radial road network pattern. There are, however, some missing links out of area bounded by the ring road of Avenida Boyacá Rd. The area of missing links are as follows: Suba, Engativá, Fontibón and Bosa. The gateways and principal roads are important element for preparation of disaster prevention with regard to securing evacuation route, and transportation of emergency supplies material. The principal road should be connected in accordance with the road classification or road hierarchy, and should be formed with the complete links, taking into account the transport operations and traffic safety. The missing links implies that it is necessary to improve such weakness by construction of new principal roads. Table 3.2.3 shows the incomplete principal road network.

Table 3.2.3 Missing Links of Principal Road by Area

District	Missing Links of Principal Road		
	Name of Rd.	Section of Ring Rd.	Section of Radial Rd.
Suba	Av. Boyaca	1. Av. San Jose-Boundary of BGT	-
	Av. Ciudad de Cali	2. Av. San Jose-Boundary of BGT 3. Autopista Medellin-Av. La Conejera	-
	Av. Longitudinal de Occidente	4. Autopista Medellin-Boundary of BGT	-
	Av. Elpolo	-	5. Av. Boyaca-Boundary of BGT
	Av. Guaymaral	-	6. Av. Longitudinal de Occidentente-Boundary of BGT
	Transversal de Suba	-	7. Av. Longitudinal de Occidentente-Boundary of BGT
Engativa & Fontibon	Av. Longitudinal de Occidente	8. Av. Jose Celestino Mutis-Av. Centenario	-
Bosa	Av. Longitudinal de Occidente	9. Av. Centenario-Boundary of BGT	-
	Av. Ciudad de Cali	10. Av. Diagonal 43 Sur-Boundary of BGT	-
	Av. Ciudad de Vellavicencio	11. Av. Primero de Mayo-Autopista del Sur	-
	Av. de las Americas	-	12. Av. Ciudad de Cali-Boundary of BGT
	Av. Primero de Mayo	-	13. Av. Ciudad de Cali-Boundary of BGT

b) Eight municipalities

The road networks of the urban areas in the eight municipalities in Cundinamarca are complex and immaturity. Besides, the maintenance of existing roads is very poor, especially for pavement and drainage facilities. In summary, the physical vulnerability of road network in the eight municipalities is shown in Table 3.2.4.

Table 3.2.4 Physical Vulnerability of Road Networks in the Eight Municipalities

Physical Vulnerability	Eight municipalities							
	La Calera	Chia	Cota	Funza	Facatativa	Madrid	Mosquera	Soacha
1. Road network is poor.	0							
2. Road network is immaturity.							0	
3. Road network is complex.								0
4. Role of principal road is unclear.		0	0			0		
5. Major gateway is insufficient in number.	0		0	0	0			
6. Major principal road is insufficient in number.			0	0			0	0
7. Major distributor as ring road is not formed.	0		0		0		0	

B. Insufficient capacity of major principal road

a) Bogotá city

The principal road network in Bogotá City is comprised of comprises V-0 class of 12 lanes, V-1 class of 10-6 lanes, V-2 class of 6 lanes and V-3 class of 6-4 lanes. The most of principal roads have more than 6- lanes road. There is, however, there are 4-lane road of major roads as well. The principal road network should be formed by 6-lane roads indicating a design capacity of about 6,000 PCU for dual both ways. Besides, the capacity of six 6 gateways from the other cities municipalities should be promoted an increased of the capacity to more than 6-–lanes road. Following gateway and principal roads are insufficient in number of lanes.

Table 3.2.5 Insufficient Capacity in Bogotá's Principal Road

Type of Roads	Name of Roads
Gateway:	La Calera Rd. (Los Patios-La Calera-Briceño Rd.)
	Avenida Villavicencio Rd.
Principal Road:	Avenida Suba Rd
	Avenida Cota Rd
	Avenida 68 Rd.
	Avenida Luis Carlos Galan
	Avenida 13 Rd.
	Avenida 11, 15, 19 Rd.

b) Eight municipalities

The number of lanes of principal roads in the eight municipalities ranges between 2-lane and 4-lane, dual both ways. These principal roads in the urban area of each city municipality are generally insufficient in number, especially the number of principal roads in the municipalities of Cota, Funza, Mosquera and Soacha.

C. Insufficient alternatives of major gateway

a) Bogotá city

In order to secure the evacuation route of emergency material supplies for Bogotá City, an alternative route of the major gateway is important. There are six major gateways entering Bogotá City. There are two gateways from Northern Colombia. However, the capacity of La Calera Rd is insufficient as an alternative route for Autopista del Norte Rd. Meanwhile, the gateways from Western Colombia are three routes, namely, Autopista Medellín Rd, Avenida Centenario Rd and Autopista Sur Rd. The alternative route of the gateway from Southern Colombia is difficult to find. As the result, the gateways, which have not any alternatives are listed as follows:

Table 3.2.6 Insufficient Alternative in Bogotá's Principal Roads

Gateway from Northern Colombia:	Autopista Norte Rd.-Tunja/Cucuta/Venezuela
Gateway from Western Colombia:	Autopista Sur Rd.-Armenia/Cali
Gateway from Southern Colombia:	Avenida Villavicencio Rd.-Villavicencio

b) Eight municipalities

The inter-city municipal roads among cities are major gateways for entering each municipality. The following inter-city roads are seen with insufficient alternative route. It is necessary to reduce such weakness by protecting the physical vulnerability of road facility.

- Inter-city municipal road of Avenida Centenario Rd. between Facatativá and Mosquera.
- Inter-city municipal road between Mosquera and Chía.

D. Lack of contingency plan for road facility

The contingency plan for the road facilities in Bogotá City was not prepared by the IDU. With regard to the prefecture road and the municipal roads, the plan is not considered by the Cundinamarca and each municipality. It is, therefore, highly recommended that the contingency plan should be planed as soon as possible.

(2) Bridge facility

Following problems and issues have been identified from the point of view of physical vulnerability about the bridge facility.

A. Design code for bridges

a) Vehicular bridges

Before 1971 the seismic effects were not considered important in the calculation and design of structures. It was likely to take horizontal forces depending on each designer's choice with reference the general parameters given by AASHTO.

It was thought that the horizontal forces should be function of the displacement of the structural elements, and the horizontal force was determined based on an established displacement. The estimation of horizontal force was settled down without certain seismic coefficients depended on geotechnical condition of the construction site.

Table 3.2.7 Chronological Evaluation of the Codes used for the Seismic Design of Bridges

Period	Code	General Considerations	Liquefaction
Before 1971	AASHTO	Coefficients that depended on the type of soil were applied as a percentage of the dead load to obtain the horizontal force.	Liquefaction was not considered in code.
1972 to 1977	AASHTO	It was supposed a relative horizontal displacement of "1" on infrastructure elements such as piles and the forces that produces. It was calculated in this way. This force was considered as the force caused by the seismic movement.	Liquefaction was not considered in code.
1977 to 1995	AASHTO	At this time AASHTO already considered two methods for seismic assessment; the first one was the static equivalent force, second method was the dynamic spectral response, specially for complex structures.	Liquefaction was considered in code. The liquefaction potential area was not identifed by officially.
1995 to at the day (2001)	Colombian Seismic Design Code for Bridges (CCP94) and Seismic microzoning of Bogotá 97.	Different methods of Seismic assessment are considered depending on the structural layout of the bridge, its importance and specially on its location within the hazard seismic zones. At the beginning of this period, the seismic movements were considered according to the Colombian Code for bridges. But since May of 2000, IDU demands that the bridges located in Bogotá should be designed and checked using the Seismic Microzoning study for the city. On last March (2001), by law, it is obligatory to use of the microzoning study. The results of the study should be applied to all kind of structures to build or repair in Bogotá.	Liquefaction is considered in the design code. The liquefaction potential area was identified in microzoning in Bogotá 97.

AASHTO propose methods of evaluation of the earthquake forces based on the experience earthquakes happened in the United States. These methods and recommendations began to be applied in Colombia in 1977 until the establishment of the Seismic Colombian code of bridges in 1995.

The methods proposed by AASHTO for this time were the equivalent static force for structures with elements of similar rigidities and that of the dynamic spectral response for complex and irregular structures. The latter method takes some importance with the creation of computer programs in the structure where dynamic spectral response was already contemplated.

Starting from the year 1995, with the appearance of the Seismic Colombian code of Bridges, the necessity of the seismic study in the bridges is bigger concern and it began to classify the structures according to its importance and to the coefficient of acceleration of the site. A certain category of seismic behavior is introduced to define the seismic procedure to use. They are the following ones: simplified seismic analysis, spectral method in the fundamental mode, spectral method with several vibration modes, method of the response against the time with acceleration families.

With the study of the seismic microzoning in Bogotá, it was settled down different spectra of acceleration area by area in Bogotá City. At the present time in all the structures that are designed or repaired in Bogotá, the microzoning should be considered.

b) Pedestrian bridges

There is not specific code for pedestrian bridge design in Colombia. Therefore, the design code of vehicular bridges is adopted with recommendations for pedestrian bridges of AASHTO.

B. Investigations of bridges

Information on bridge investigation is collected by the Study Team. Table.3.2.8 shows number of investigated bridges in the Study Area.

Table 3.2.8 Number of Investigated Bridges in the Study Area

	Bogotá		Eight municipalities	
	Vehicular	Pedestrian (Flyover)	Vehicular	Pedestrian
Organization	IDU		INVIAS	Municipalities and concession
Total number of bridges	177	146	36	19
Visuale inspection bridge	122	134	17	0
Were re-calculated bridge	44	58	0	0
Replaced or reinforcement bridge	42	58	0	0
Replaced or reinforced bridge	16	33	0	0

Source: JICA Study Team, 2001

a) Vehicular bridges in Bogotá

70 of vehicular flyover bridges and 52 vehicular river bridges were investigated by IDU in 1998. This investigation consisted of two steps. The first one was visual inspection, which screened bridges, which should be re-calculated. The second one was re-calculation. The bridges, have any problems, are listed in reinforcement list or replacement list.

Comments on this investigation are as follow.

- The investigation did not cover all vehicular bridges. 70% of total bridges were inspected by visual inspection and 25% of that are recalculated.
- The visual inspection did not concern seismic matter.
- The re-calculations were appropriate since it followed latest design code and using the design acceleration of micro-zoning study 97.

Re-calculation of the structure of vehicular bridges takes long time and is far difficult than that of pedestrian bridges. Re-calculation, however, is important in order to clarify the portion where modification is necessary or to clarify whether reconstruction or replacement of bridge is required or not.

b) Recommendation

- Seismic diagnosis is recommended to make re-calculation priority.
- Establishment of simple visual seismic diagnosis is recommended. It is useful to modify a Japanese seismic diagnosis scheme.

c) Pedestrian bridges in Bogotá

All pedestrian bridges in Bogotá have been investigated by IDU in 1998. Earthquake-resistance of all bridge was re-calculated according to proposed ground acceleration of micro-zoning study 1998. A scheme of reinforcement and replacement of pedestrian bridges is on going currently. Figure 3.2.7 shows the current situation of pedestrian bridges according to the result of investigation 1998.

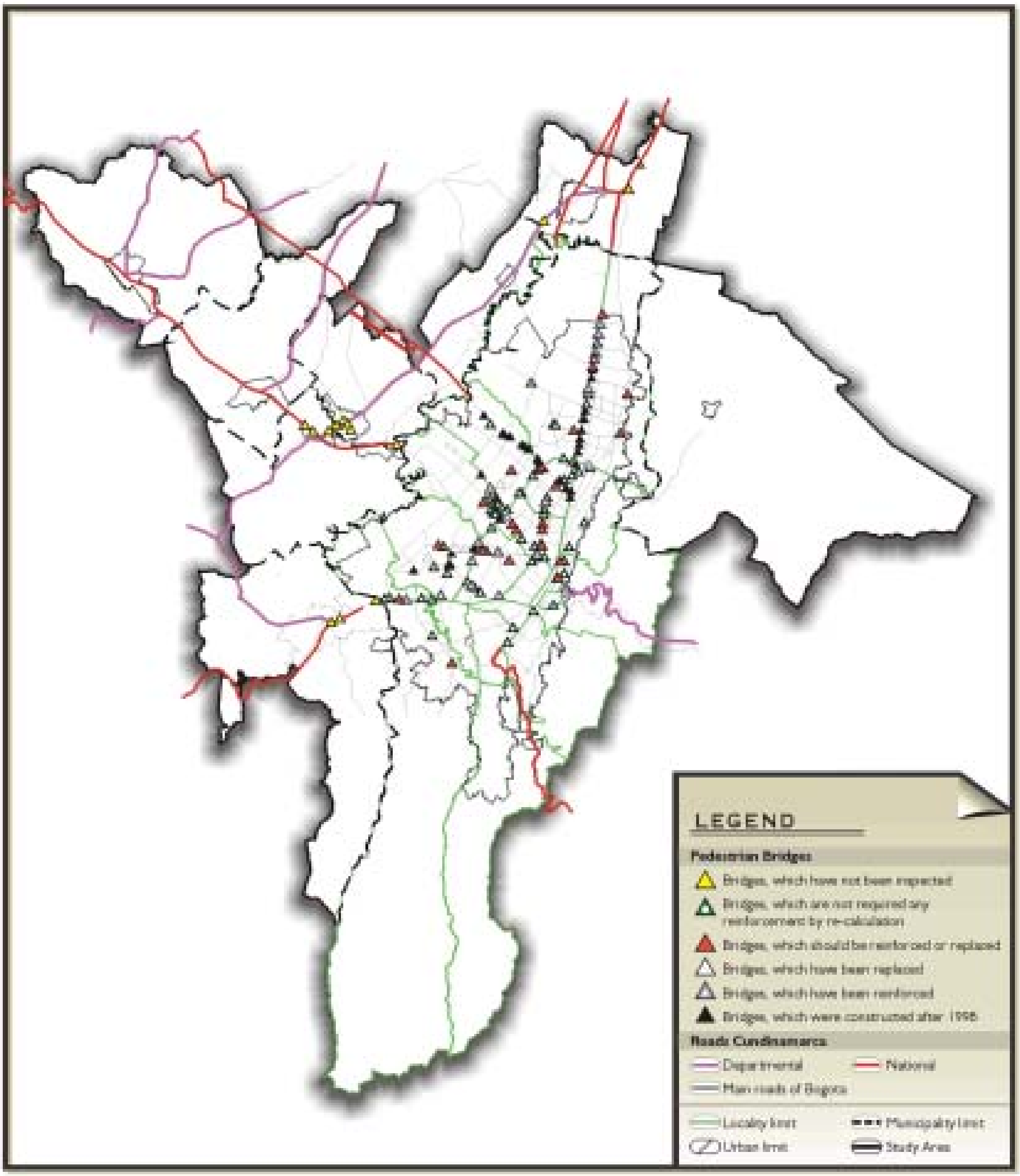


Figure 3.2.7 Pedestrian Bridge Situation according to IDU Investigation 1998

The investigation is appropriate for super structure. However, detail information on foundation and liquefaction is not available during the inspection. Therefore, IDU intends to investigate foundation of all of pedestrian bridges.

The Study Team recommend that liquefaction factor should be included in the investigation on foundation for bridges, which is located in liquefaction potential area.

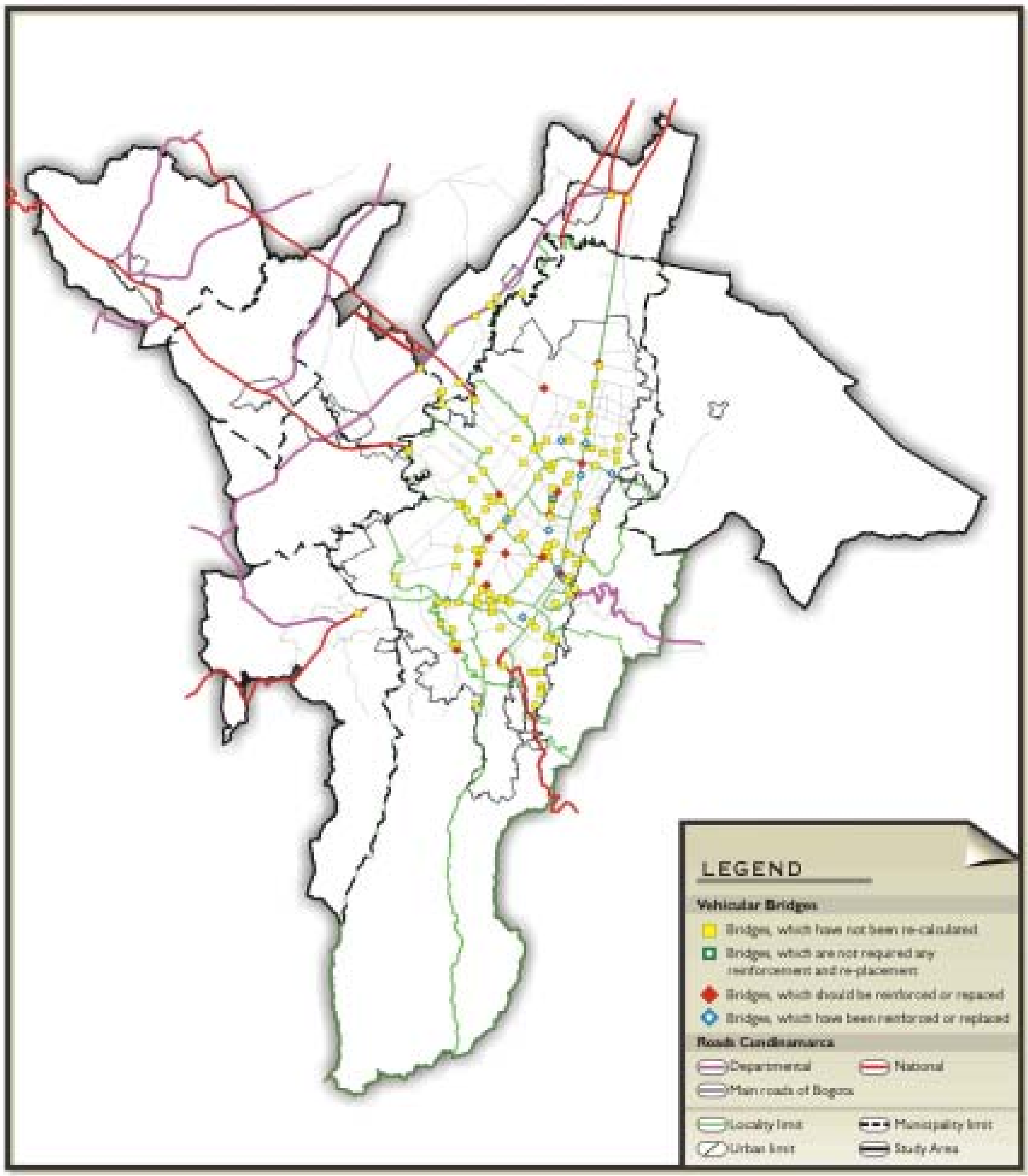


Figure 3.2.8 Vehicular Bridge Situation according to IDU Investigation 1998

C. Vehicular bridges in the eight municipalities

Vehicular bridges in the eight municipalities are river bridges except flyovers in Chía. Flyovers in Chía are relatively new. Therefore, the reliability of the flyover is relatively high.

On the other hand, some of river bridges are very old. It is doubtful that old bridges have enough seismic resistance.

D. Pedestrian bridges in the eight municipalities

Structure of most pedestrian bridges in the eight municipalities is simple beam. The characteristics of the pedestrian bridges are summarized as follows:

- Risk of destruction is high since the pier is slender.
- Risk of collapse is high since the seat width is very narrow.

(3) Railway facility

Following problems and issues have been identified from the point of view of physical vulnerability about the railway facility:

- Deterioration of railway facilities.
- Poor transport capacity, and
- Poor operation system.

3.2.2 Social and Economic Vulnerability

1) General

The urbanization is inevitable phenomena in the whole countries. As the economy grows, the people tend to live in urban places. The urbanized area provides better living conditions and job opportunities for the people. The economic activities in the urbanized area have diversified to grow industrial and service sectors and have become more links to other areas within the country as well as oversea countries.

Within the urban area, the transportation system has developed to commute people from living place to working place. Information and communication network also has developed to support the industries. The city expansion, however, has not considered the risks for the urbanization. Urban area has formulated risks associated with their nature of expansion. Therefore, it should be recognized that the urban area itself produces the risks for the natural disasters.

In this section, vulnerabilities for the urbanized area have analyzed in three categories: social, economic and environmental aspects. Those items are interrelated to formulate compounded vulnerabilities for the urbanized area.

2) Social Vulnerability

(1) Definition

The measurement of social vulnerability is still under the development. Attention has been paid on special categories of vulnerable groups: livelihoods at risk, perception of risk, existence of local institutions and level of poverty.[3-2-2] In this study, social vulnerability is defined by using

[3-2-2] Carter, W. Nick (1991) Disaster Management A Disaster Manager's Handbook, Asian Development Bank

several variables of social class and population, which includes expansion of urban population, age composition and density

(2) Social class

Reference is made to Section 2.2.3 of this report. In poverty level of the communities, classification by the *estrato* will be reliable indicators of the Study Area. Colombia has established social-economic class based on residential area's characteristics and the tariff of the public utilities such as electricity, water supply, sewage and telephone. The low estrato has obtained low tariff structure of the public utility based on the local government regulation, while high estrato has to pay higher utility tariff to cover the low estrato. Therefore, *estrato* can be used for the general guideline for the social classification in Colombia. It implies that low estrato is relatively low-income community, which means socially vulnerable.

The social vulnerability is defined as the poverty level of organization. One of indexes to define the poverty level is developed by the Mision Social, Department of National Planning for measuring poverty level, which called *Sistema de Seleccion de Beneficiarios para Programas Sociales* (SISBEN). SISBEN was designed to provide local governments for the targeting of social expenditures to the most poor and vulnerable groups. DAPD was carried out survey on December 2000 and shows the results. SISBEN classified the six groups based on the survey results. According to SISBEN classification, level 1 and 2 is classified as poverty. The results show that more than 25 percent of surveyed population are classified as level 1 and 2. In estrato 1 and 2, the share of level 1 and 2 population has become 29 percent.

A. Level 1

Corresponds to families that are in extreme poverty conditions, it means that families with two or more basic necessities are unsatisfied. As the results of survey, the localities of Ciudad Bolivar and Usme show the biggest percentage of population in level 1.

B. Level 2

For Level 2, families with one basic necessity are unsatisfied. From the surveyed results, the localities with more people in level 2 of SISBEN are Ciudad Bolivar, Usme, Suba, Kennedy and San Cristobal.

The Table 3.2.9 shows the distribution of poor population defined by SISBEN.

Table 3.2.9 Summary of Poverty Population by SISBEN

Locality	Population		Population		Population	
	Level 1	(%)	Level 2	(%)	Level 3	(%)
Usaquén	4,871	4.23	32,096	4.37	61,080	4.10
Chapinero	1,755	1.53	6,699	0.91	10,064	0.68
Santa fe	6,111	5.31	38,022	5.18	58,404	3.92
San Cristobal	7,125	6.19	56,792	7.74	114,960	7.72
Usme	20,017	17.40	96,593	13.16	143,306	9.63
Tunjuelito	901	0.78	22,289	3.04	69,433	4.66
Bosa	6,716	5.84	74,327	10.12	155,153	10.42
Kennedy	7,741	6.73	56,089	7.64	146,818	9.86
Fontibón	841	0.73	13,164	1.79	51,759	3.48
Engativá	1,841	1.60	34,052	4.64	120,023	8.06
Suba	5,018	4.36	65,782	8.96	150,281	10.10
Barrios Unidos	1,301	1.13	8,319	1.13	32,405	2.18
Teusaquillo	67	0.06	526	0.07	1,511	0.10
Los Mártires	1,356	1.18	10,471	1.43	21,905	1.47
Antonio Nariño	275	0.24	4,501	0.61	14,475	0.97
Puente Aranda	1,589	1.38	8,326	1.13	25,770	1.73
La Candelaria	522	0.45	5,855	0.80	9,092	0.61
Rafael Uribe	5,624	4.89	47,838	6.52	95,592	6.42
Ciudad Bolívar	38,444	33.42	152,038	20.71	206,428	13.87
Sumapaz	2,903	2.52	337	0.05	118	0.01
Total	**115,018**	**99.97**	**734,116**	**100.00**	**1488,577**	**100.00**

Source: Información para el Plan Local 2001

The table shows that level 1 is concentrated in Ciudad Bolivar, followed by the Usme. In Ciudad Bolivar, the level 1 and 2 population exceed more than 50 percent of total population. It means that more level 1 and 2 population has concentrated locality would be high-risk area.

(2) Population

A. Urbanization

The urban area has experienced rapid urban population increase. Rapid urban population increase has led to many urban problems, such as transportation, housing, public facilities etc. As urban population has increased, the linkage of the community has become weak. After a disaster, the community organization should have played important role. The most of important social issue is formulation of community level organization for the disaster management. The past experience shows that community level search and rescue operation saves many lives in the community.

Bogotá City has experienced rapid urban population increase during 1960s and the annual average population increase has reached at more than 7 percent. Reasons of the population increase are natural increase associate with improvement of infant mortality rate. For social increase, it can be observed refugee of the civil war in Colombia, although the economic reasons, which can be the essential reasons for migration in other countries, are one of the factors. The population of Bogotá was only 660 thousands in 1951 and it became more than 2.8 millions in 1973. It is more than four times increase during 22 years. Since then, Bogotá City as well as adjacent Cundinamarca municipalities has experienced population increase. The share of population in Bogotá City to national population has become 16.1 percent in 1993. According to DPAD estimation, Bogotá City will increase population about 130,000 annually.

B. Population composition

The population composition is another issues. The past experience shows that the children and elderly population would be high risk for the disaster. It is important to identify the high-risk personnel.

Table 3.2.10 Distribution of High Risk Personnel

Locality	0 - 4 years	% total Bogota	55 years and more	% total Bogota	Total Population in Risk	Total Population Locality	% total Bogota
USAQUEN	45,191	6.53	43,136	6.94	88,327	421,320	6.60
% population of locality	10.73		10.24		21		
CHAPINERO	7,700	1.11	18,736	3.02	26,436	122,991	1.93
% population of locality	6.26		15.23		21		
SANTAFE	10,836	1.57	11,262	1.81	22,098	107,044	1.68
% population of locality	10.12		10.52		21		
SAN CRISTOBAL	53,676	7.76	42,173	6.79	95,849	455,028	7.13
% population of locality	11.8		9.27		21		
USME	33,103	4.78	15,182	2.44	48,285	244,270	3.83
% population of locality	13.55		6.22		20		
TUNJUELITO	21,530	3.11	18,697	3.01	40,227	204,367	3.20
% population of locality	10.53		9.15		20		
BOSA	52,330	7.56	23,054	3.71	75,384	410,099	6.43
% population of locality	12.76		5.62		18		
KENNEDY	97,903	14.15	93,457	15.04	191,360	912,781	14.31
% population of locality	10.73		10.24		21		
FONTIBON	29,898	4.32	28,540	4.59	58,438	278,746	4.37
% population of locality	10.73		10.24		21		
ENGATIVA	80,343	11.61	76,695	12.35	157,038	749,068	11.74
% population of locality	10.73		10.24		21		
SUBA	75,780	10.95	72,341	11.64	148,121	706,528	11.08
% population of locality	10.73		10.24		21		
BARRIOS UNIDOS	12,870	1.86	26,068	4.20	38,938	176,552	2.77
% population of locality	7.29		14.77		22		
TEUSAQUILLO	7,225	1.04	20,173	3.25	27,398	126,125	1.98
% population of locality	5.73		15.99		22		
LOS MARTIRES	7,761	1.12	11,683	1.88	19,444	95,541	1.50
% population of locality	8.12		12.23		20		
ANTONIO NARIÑO	8,441	1.22	11,815	1.90	20,256	98,355	1.54
% population of locality	8.58		12.01		21		
PUENTE ARANDA	24,914	3.60	30,494	4.91	55,408	282,491	4.43
% population of locality	8.82		10.79		20		
LA CANDELARIA	2,336	0.34	3,511	0.57	5,847	27,450	0.43
% population of locality	8.51		12.79		21		
RAFAEL URIBE	41,254	5.96	39,379	6.34	80,633	384,623	6.03
% population of locality	10.73		10.24		21		
CIUDAD BOLIVAR	78,853	11.39	34,641	5.58	113,494	575,549	9.02
% population of locality	13.7		6.02		20		
TOTAL BOGOTA	692,120	100.00	621,234	100.00	1,313,354	6,378,928	100.00
% population of Bogotá	10.85		9.74		21		

Source: Informacion para el Plan Local 2001

The high-risk personnel are found in the whole Bogotá City at rate of about 20 percent. It is not clear which locality has more risky age structure than that of others.

C. Density

Table 3.2.11 shows that average population density in estrato 2 and 3 is more than 400 persons/ha, while average population density in estrato 5 and 6 is approximately 100 persons/ha. Estrato 1 and 2 is four times more populous in comparison with estrato 5 and 6. There is approximately 300 persons/ha in Estrato 1. The low estrato community would be socially vulnerable for having relatively low income with high population density.

Table 3.2.11 Population Distribution by *Estrato*

LOCALITY		Not Classify	ESTRATO 1	2	3	4	5	6	TOTAL
1. USAQUEN	Area (Ha)	900.70	60.39	228.20	342.13	354.36	277.88	382.27	2,545.93
	Population	9,521	11,395	37,943	108,639	96,290	53,950	69,535	387,271
	Density	10.57	188.67	166.27	317.54	271.73	194.15	181.90	152.11
2. CHAPINERO	Area (Ha)	101.63	33.84	146.74	53.48	155.38	96.65	301.05	888.77
	Population	1,587	5,680	10,638	9,899	32,759	14,007	48,422	122,991
	Density	15.62	167.83	72.49	185.10	210.83	144.93	160.84	138.38
3. SANTA FE	Area (Ha)	71.41	13.53	167.77	130.40	8.69	0.93		392.75
	Population	1,349	3,389	72,690	26,213	3,393	11		107,044
	Density	18.89	250.45	433.26	201.01	390.19	11.84		272.55
4. SAN CRISTOBAL	Area (Ha)	99.02	71.51	586.07	153.48				910.08
	Population	4,370	34,029	341,107	66,030				445,535
	Density	44.13	475.84	582.02	430.22				489.56
5. USME	Area (Ha)	163.98	365.35	216.86					746.20
	Population	2,074	58,929	161,912					222,915
	Density	12.65	161.29	746.62					298.73
6. TUNJUELITO	Area (Ha)	226.75	3.71	231.60	128.45				590.51
	Population	2,745	26	130,014	71,582				204,367
	Density	12.11	6.92	561.37	557.29				346.09
7. BOSA	Area (Ha)	214.00	142.93	734.49	29.47				1,120.89
	Population	1,588	2,749	286,655	20,707				311,698
	Density	7.42	19.23	390.28	702.61				278.08
8. KENNEDY	Area (Ha)	651.33	22.28	564.46	846.48	20.29			2,104.83
	Population	5,935	12,905	327,347	486,060	7,790			840,036
	Density	9.11	579.34	579.93	574.21	383.98			399.10
9. FONTIBON	Area (Ha)	830.94		305.39	398.87	137.16			1,672.36
	Population	2,555		17,509	180,677	40,631			241,372
	Density	3.07		57.33	452.97	296.24			144.33
10. ENGATIVA	Area (Ha)	637.18	10.27	359.91	1082.64	89.76			2,179.76
	Population	8,386	4,351	75,276	596,039	27,988			712,040
	Density	13.16	423.65	209.15	550.54	311.80			326.66
11. SUBA	Area (Ha)	709.27	8.67	829.18	587.84	357.11	675.08	395.79	3,562.92
	Population	6,243	1,788	216,349	223,336	79,140	96,887	10,926	634,669
	Density	8.80	206.35	260.92	379.93	221.62	143.52	27.61	178.13
12. BARRIOS UNIDOS	Area (Ha)	241.73	0.06	21.62	296.40	222.58	22.41		804.80
	Population	2,207			112,634	57,744	3,966		176,552
	Density	9.13			380.00	259.43	176.99		219.37
13. TEUSAQUILLO	Area (Ha)	479.24		14.50	93.99	367.37	21.72		976.82
	Population	613		18	22,291	95,299	7,905		126,125
	Density	1.28		1.25	237.15	259.41	364.00		129.12
14. LOS MARTIRES	Area (Ha)	84.93		19.92	316.97	10.55			432.37
	Population	510		5,185	85,405	4,441			95,541
	Density	6.01		260.33	269.44	420.93			220.97
15. ANTONIO NARINO	Area (Ha)	59.50		8.47	252.42				320.39
	Population	98		7,833	90,424				98,355
	Density	1.64		925.14	358.23				306.98
16. PUENTE ARANDA	Area (Ha)	464.83	0.20	10.15	640.90				1,116.07
	Population	2,283	171	709	279,329				282,491
	Density	4.91	839.49	69.83	435.84				253.11
17. LA CANDELARIA	Area (Ha)	41.00		49.07	33.47				123.54
	Population	980		18,190	8,280				27,450
	Density	23.89		370.72	247.37				222.19
18. RAFAEL URIBE U	Area (Ha)	68.10	36.25	224.18	364.15				692.67
	Population	3,628	18,578	166,078	194,517				382,801
	Density	53.27	512.55	740.84	534.17				552.65
19. CIUDAD BOLIVAR	Area (Ha)	143.39	561.42	272.62	56.82				1,034.25
	Population	5,395	231,771	239,081	21,929				498,177
	Density	37.63	412.83	876.96	385.98				481.68
TOTAL	Area (Ha)	6,188.93	1,330.41	4,991.20	5,808.36	1,723.23	1,094.66	1,079.11	22,215.92
	Population	62,065	385,759	2,114,533	2,603,991	445,473	176,725	128,883	5,917,430
	Percentage	1.05	6.52	35.73	44.01	7.53	2.99	2.18	100.00
	Density	10.03	289.96	423.65	448.32	258.51	161.44	119.43	266.36

Note: 1) The area classified as non-residential areas such as factory, commercial and parks.
Source : DAPD. Subdirección de Desarrollo Humano y Progreso Social

It is pointed out that the southern part of Bogotá shows a higher population density of more than 400 persons/ha and the most populous localities include San Cristobal, Rafael Uribe and Ciudad Bolivar. Despite the estrato, these localities show high population densities in addition to high population increases in the last five years as well. Therefore, those localities may expand residential development areas and newly developed areas are likely to be pose higher risky area due to low land prices.

3) Economic Vulnerability

(1) Definition

Economic vulnerability measures the risk of hazards causing losses to economic assets and processes. It focuses on evaluating the direct loss potential such as damage or destruction of physical and social infrastructure and its replacement cost. Indirect loss potential includes impact on lost production, employment, vital services and income-earning activities. The secondary loss is defined as epidemics, inflation, and income disparities and isolated outlying area[3-2-2].

In this study, economic loss is calculated for the physical assets of buildings, bridges and vital lifeline. In the case of commerce and industry, the direct economic losses are buildings, machinery, stocks and products, yet there is a limitation to estimate those losses excepting building assets. The secondary losses are difficult to estimate.

(2) Economic loss

The economic activities have progressed in the urban areas. Concentration of economic activities would benefit to whole economic sector, because urban area could provide services products in low prices. The urban area usually imports food and agricultural commodities from outside area and export industrial goods and services. Those economic linkages have developed between urban and rural areas.

Bogotá City is the economic center of Colombia and it produces more than 23 percent of Gross Domestic Product (GDP) in 1998. The geological location of Bogotá City has to depending on energy, agricultural commodities, and consumer goods from the outside of Bogotá. The statistics shows that Bogotá City produces high value added products and service goods.

The disaster damage on the economic sector in Bogotá City would lead economic confusion to the countries. The economic damage would have great influence of the economic activities of whole economy, because economic linkages have already established between Bogotá City and other regions. The economic damage would extend as delay of economic recovery activities. Therefore, disaster damage on economic sector would not only Bogotá City but also whole economic activities.

[3-2-2] Carlos Eduardo Velez, Elkin Castaño and Ruthanne Deutsch (1998), An Economic Interpretation of Colombia's SISBEN: A Composite Welfare Index Derived from the Optimal Scaling Algorithm
Carter, W Nick (1991) Disaster Management: A Disaster Manager's Handbook, Asian Development Bank, Manila, Philippines

(3) Estimation of direct economic losses

A. Building

In order to estimate economic losses, the building damage can be calculated from the building damage estimation. It is estimated at 100 percent of building value for severely damaged or destroyed buildings.

The building value is derived from the cadastral value of the building. The purposes of the cadastral value are property tax collection and it represents real value of the building. Therefore, the cadastral value is used for the estimation.

B. Infrastructure

The value of bridge and vital infrastructure is estimated at construction costs. The replacement cost is derived from the actual construction costs in the Study Area.

C. Results

The estimation results are shown in Chapter 4.2 of this report.

4) Environmental Vulnerability

(1) Definition

Environmental vulnerability can be categorized into natural and social aspects. A general methodology to measure environmental vulnerability is still being developed. In this study, environmental risks can be categorized into three items:

- Natural Conditions.
- Location of industrial area for industrial disaster; and
- Waste management.

(2) Natural conditions

The urbanized area has developed in the relatively flat area because of easy construction of buildings and facilities. Those areas are usually composed of the river deposit and reclamation of lake and sea. The soft soil area in the urban area can be observed in the many urbanized areas.

The Study Area has situated in the soft soil area. The composition of the lake clay in the central part of plain is over 500m deep. This study found that the approximately 25% of the Study Area is classified as soft lake deposit area and 4% of land falls into sandy soil area, where it is the problems of the liquefaction. Moreover, the edge of the mountain area has high risk of amplification of seismic intensity, which shares about 13 percent of the Study Area.

(3) Industrial area

The distribution of the industrial facilities shows that the eight localities have 78% of the total industrial facilities. The eight localities include Puente Aranda, Fontibón, Kennedy, Enqativá, Barrios Unidos, Usaquén, Los Mártires and Suba. The area has faced great potential for leakage, fire, spilling and explosion. Puente Aranda has 23 % of the industrial facilities and high potential for disaster events. The industrial facilities are located in the designated area, yet those areas have developed since then. The land use has changed to develop more attention toward residential and industrial mixed use. Those facilities are mixed among with the residential areas and have great impact on natural and social environments when industrial disaster has happened.

(4) Waste management

After the earthquake disaster, the debris disposal would be a problem and disposal place should be determined before a disaster. After the Armenia earthquake, the amount of debris was 1.8 million m^3 in population of 280 thousands, according to the Armenian government report. If this figure would apply to the Bogotá Metropolitan Area, it would become 41 million m^3. Therefore, the earthquake damage would have huge environmental impacts on the Study Area.

3.3 Regional Risk Analysis

3.3.1 General

Prior to designing preventive programs for disasters, it is important to know which type of risk each region has to face.

The objective of this analysis in this part of the study is to determine the regional risk by disaster type. The result will be used specifically for two purposes as follows:

- Classification of risk to each locality and municipality; and
- Selection of priority UPZ for earthquake risk.

3.3.2 Methods of Analysis

1) General

Four types of disasters, namely, earthquake, landslide, flood, and fire in industrial facilities were analyzed. The results of analysis were used to produce two major outputs: a map of degree of regional risk, and a map of priority UPZ distribution.

Analysis was done by three steps, as shown in Figure 3.3.1. Step 1 determines each disaster's risk component with the scale of 1 to 5. Step 2 investigates the integrated risk of each disaster also with the scale of 1 to 5. Step 3 analyzes the degree of risk to each UPZ. However, in this section, the result of analysis only until step two is presented. Step 3 is discussed later in section 5.2.2.

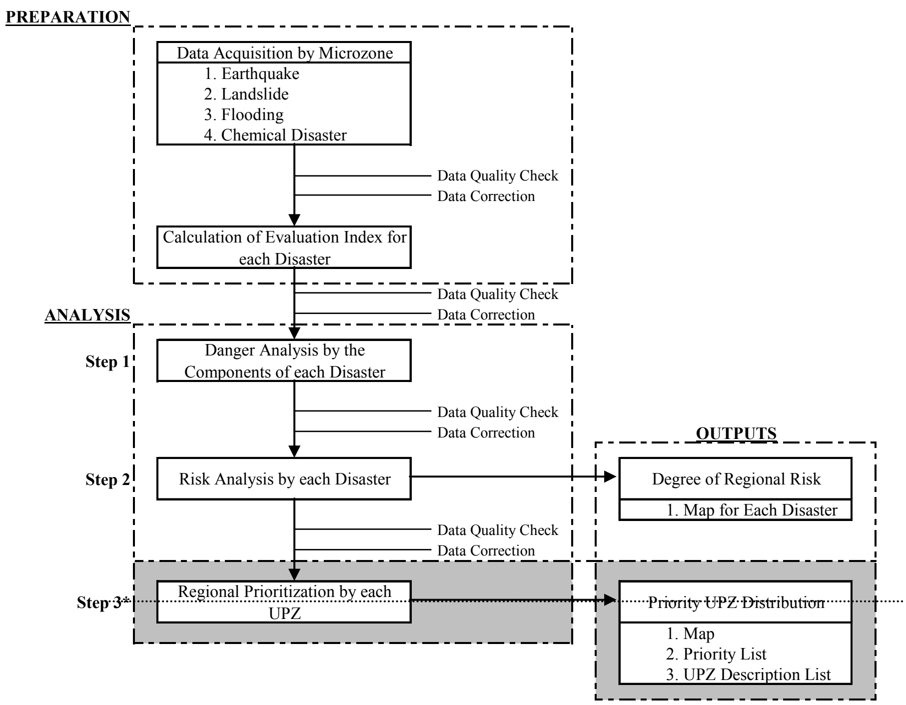


Figure 3.3.1 Flowchart of the Regional Risk Analysis

For the analysis in this section, the microzoning for the Study was used in general. Basically, the analysis took into consideration only the urbanized area. The rural area was excluded because its population is small and thus the risk is not high.

Table 3.3.1 shows the methods for analyzing the regional degree of risk for all the disaster types, and their significance for the analysis is provided in the latter section.

2) Earthquake

For the regional risk analysis of earthquakes, the Guayuriba fault (medium distance) model was applied, because the damage estimation with this model was considered most severe by this study.

For the analysis, following procedures have been adopted:

For step 1, risk classification by the components of each disaster, three variables were used for this event. The variables are:

- degree of risk for buildings.
- degree of risk for human casualties, and
- degree of risk for evacuation.

Variable used to the building risk was the result by the damage estimation on the percentile of the severely damaged buildings. Within the analysis on the vulnerability analysis of building damage, building structure type, such as wood, prefabrication, masonry and reinforced concrete, number of stories, and estrato has been taken into consideration.

Variable used to the human casualty degree is the population density of each microzone.

Degree of danger for evacuation, which indicates the difficulty of evacuation in case of emergency, was calculated for the third index. In this, percentage of open space to the total area for microzone was calculated. The open space here defines the road and the public parks, and undeveloped open space is not included.

Table 3.3.1 Methods for Classification of Regional Degree of Risk

Degree of Risk	Items	Index	Descriptions	Points
Earthquake	Building Damage	Heavily damaged building damage ratio	Results from the damage estimation.	0 < 20% to 1 20 < 40% to 2 40 < 60% to 3 60 < 80% to 4 80 < 100% to5
	Human Causality	Population density	Population Density of each microzone.	0 < 150 to 1 150 < 300 to 2 300 < 450 to 3 450 < 600 to 4 600 < up to5
	Evacuation	Rate of open space	Open space ratio (Open space + Road space)/Total area of microzone)	80 < 100% to 1 60 < 80% to 2 40 < 60% to 3 20 < 40% to 4 0 < 20% to 5
Landslide	Building Damage	Percent of the risk area out of the total area of the microzone.	Physical Degree of Danger = (Danger Area ha (km^2)) / Total Area in the Microzone	0 < 20 to 1 20 < 40 to 2 40 < 60 to 3 60 < 80 to 4 80 < 100 to 5
Flood	Building Damage	Percentage of the building located in the flooding risk area.	Degree of Danger for Buildings = (Area of H in unit×2) + (Area of M in unit×1.5) + (Area of L in unit×1.2))/Total Area of Unit×100	0 < 40 to 1 40 < 80 to 2 80 < 120 to 3 60 < 80 to 4 80 < 100 to 5
	Human Casualty	Number of people living in suffering from the disaster.	1) No. of Possible Affected Population in Unit = Σ (Population Density of the unit× ha (km^2) of dangerous area in unit × probability) 2) Degree of Danger for Human Casualties = No. of Possible Affected Population / Total Population in the Unit	0 < 2 to 1 2 < 4 to 2 4 < 6 to 3 6 < 8 to 4 8 <10 to 5
Fire	Fire Breakout ratio	Rate of fire break out for the industrial facilities	Result of the fire break out rate of damage estimation for an earthquake	0 < 0.2 to 1 0.2 < 0.4 to 2 0.4 < 0.6 to 3 0.6 < 0.8 to 4 0.8 < 1.0 to 5

3) Landslide

For the regional risk analysis of landslide, DPAE's hazard map for landslides was used. The high hazard area was considered as the physical high-risk zone. Also, the data accumulated throughout this study of high-risk landslide-points were integrated into the consideration of giving regional priority.

For the analysis, Table 3.3.1 can be also referred for the procedures and detailed description of the calculation. For step 1, risk classification by the degree of risk for building was only used. First, the ratio of area where distinguished as danger area to total area in the microzone was calculated. Then, the landslide points where evaluated as risky areas, were overlaid to the calculated microzone for the conclusion.

4) Flood

For the regional risk analysis of flood, existing hazard maps were used for Bogotá City and some of the municipalities of Cundinamarca.

For the analysis, Table 3.3.1 can be referred for the detailed methods and descriptions. For step 1, two variables were used for this event. The variables are:

- degree of danger for buildings, and
- degree of danger of human casualties.

For the degree of risk for buildings, percentage of the buildings located in the flood risk area was calculated by microzone. Within this calculation, flood areas where evaluated as high, medium, and low within the microzone were weighted, and then divided by the total area of the microzone.

For calculating the degree of human casualties, the number of people with the possibility of and probability of suffering from the disaster in the microzone was used. It was calculated by two steps: First, the possible affected population in the microzone was calculated. This included the population density, hectares of danger area, and the flood return probability. Next, the degree of danger for human casualties was calculated. In this, number of possible affected population was divided by the total population in the microzone for each microzone.

5) Fire in Industrial Facilities

For the regional risk analysis of industry, result of fire outbreak risk-points in case of an earthquake was used. It was calculated by the Study Team for the industrial facilities. The Guayuriba Fault (medium distance) Model was also applied, because the damage estimation with this model was considered most severe.

Result was used to generate a map on the degree of risk for industry where the darker color indicates a higher risk.

3.3.3 Results

Brief descriptions on the results for all the disaster events are given below. Appendix 3.3.1 contains a rough indicator for the map of degree of risk. This can be referred with the maps of degree of regional risks for earthquake, landslide, flood and industry. However, the result of the risk level is only a relative comparison within the Study Area; therefore, it does not mean that the area with low risk is safe in anyway.

A. Earthquake

In this event, results from steps 1 and 2 are presented as follows.

- Step 1: Risk classification by the components of each disaster.
- Step 2: Risk classification by each disaster.

For the result of step 1, risk analysis on buildings, human casualties and evacuation are shown in Appendices 3.3.2, 3.3.3 and 3.3.4, respectively. These maps show which microzones are relatively at high risk and which are not by each index. With the degree of danger for buildings, the zones with building collapse areas are distributed all over the Bogotá Metropolitan Area, and the high collapse rate for risk 5 is mainly distributed in the southern part of Bogotá and Cota.

With the degree of danger for human casualties, it is obvious that the highly dense areas or the high-risk area of 4 and 5 are concentrated to the southern part of Bogotá and Soacha. There are several highly dense areas in the north-western part.

Regarding the degree of danger of evacuation, high-risk areas are distributed in the very southern part, the northern part excluding the environmental protection area, and the eastern part close to the hills.

A result of degree of risk is shown in Figure 3.3.2. In this figure, the high-risk area of point 5 is distributed in the south, point 4 in the south and several in the north, and in the municipalities of Soacha, Facatativá, and Cota.

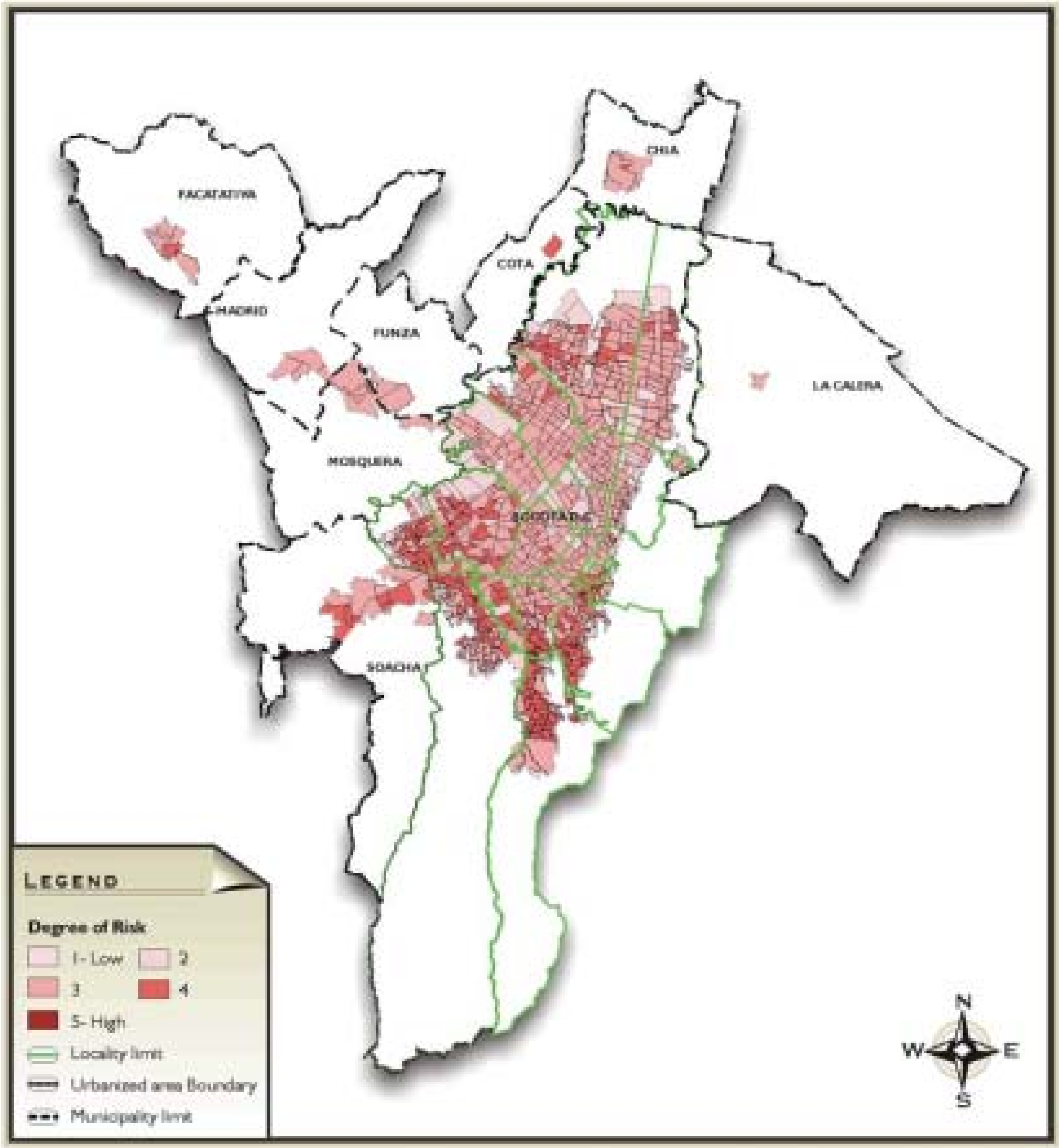


Figure 3.3.2 Degree of Regional Risk for Earthquake

B. Landslide

Figure 3.3.3 shows the result of the analysis of landslide. The microzone which includes more of the high-risk area should consider measures for landslides. Also, the points selected as high-risk areas through the study are overlaid, showing the region requiring landslide measures. Although high-risk evaluated landslide-points are fairly distributed to the locality of high-risk zone, it shows that the high-risk landslide-points are more concentrated in the southern part of Bogotá.

C. Flood

Figure 3.3.4 shows the result of risk analysis of flood. In this figure, it is clear that all the area near the Rio Bogotá has to consider flood measures; however, the north western part of Bogotá has higher risk as shown by the analysis.

D. Fire in Industrial Facilities

Figure 3.3.5 shows the result of risk distribution of industrial facilities. It is obvious that the risk area of industry is concentrated in the area of industrial zones.

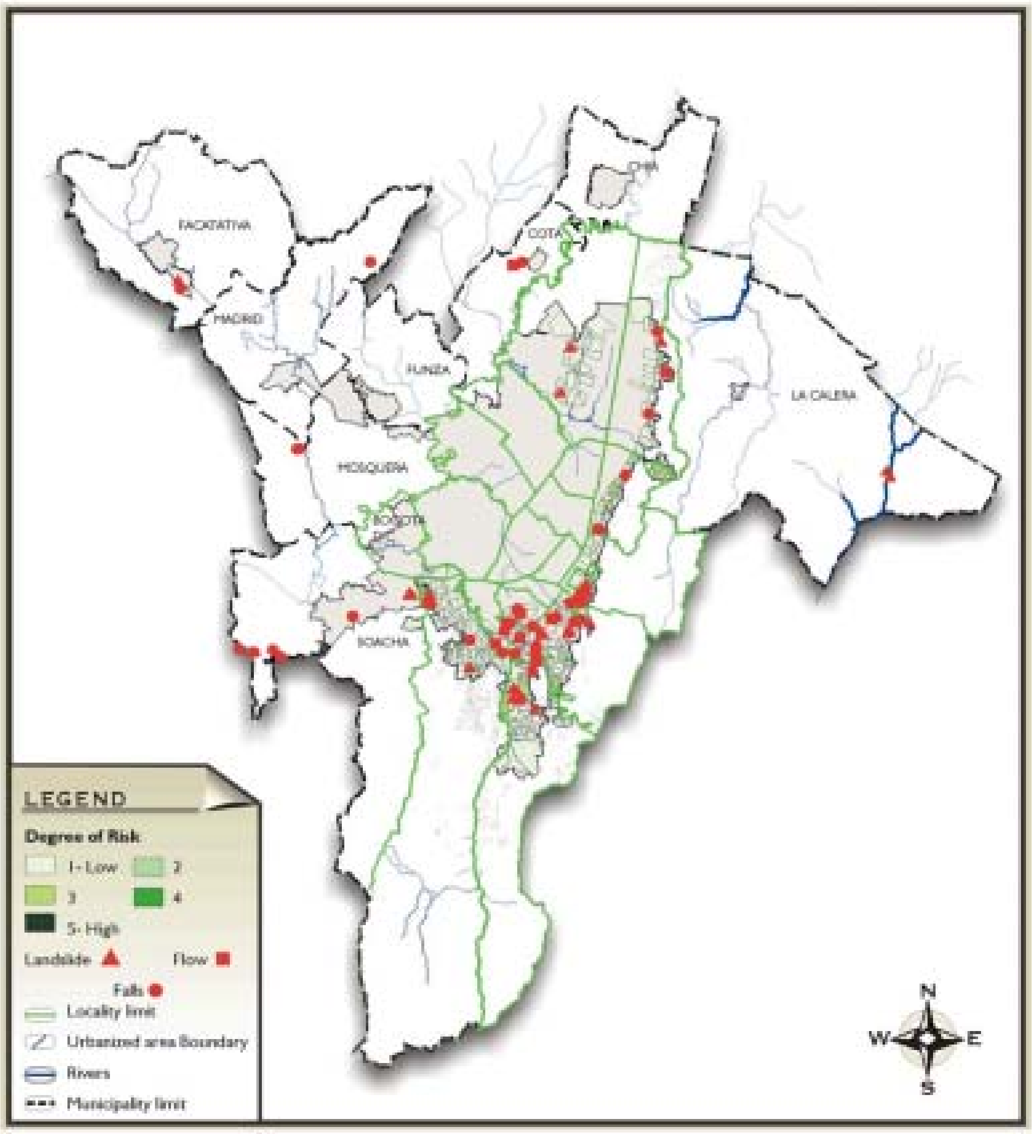


Figure 3.3.3 Degree of Regional Risk for Landslide

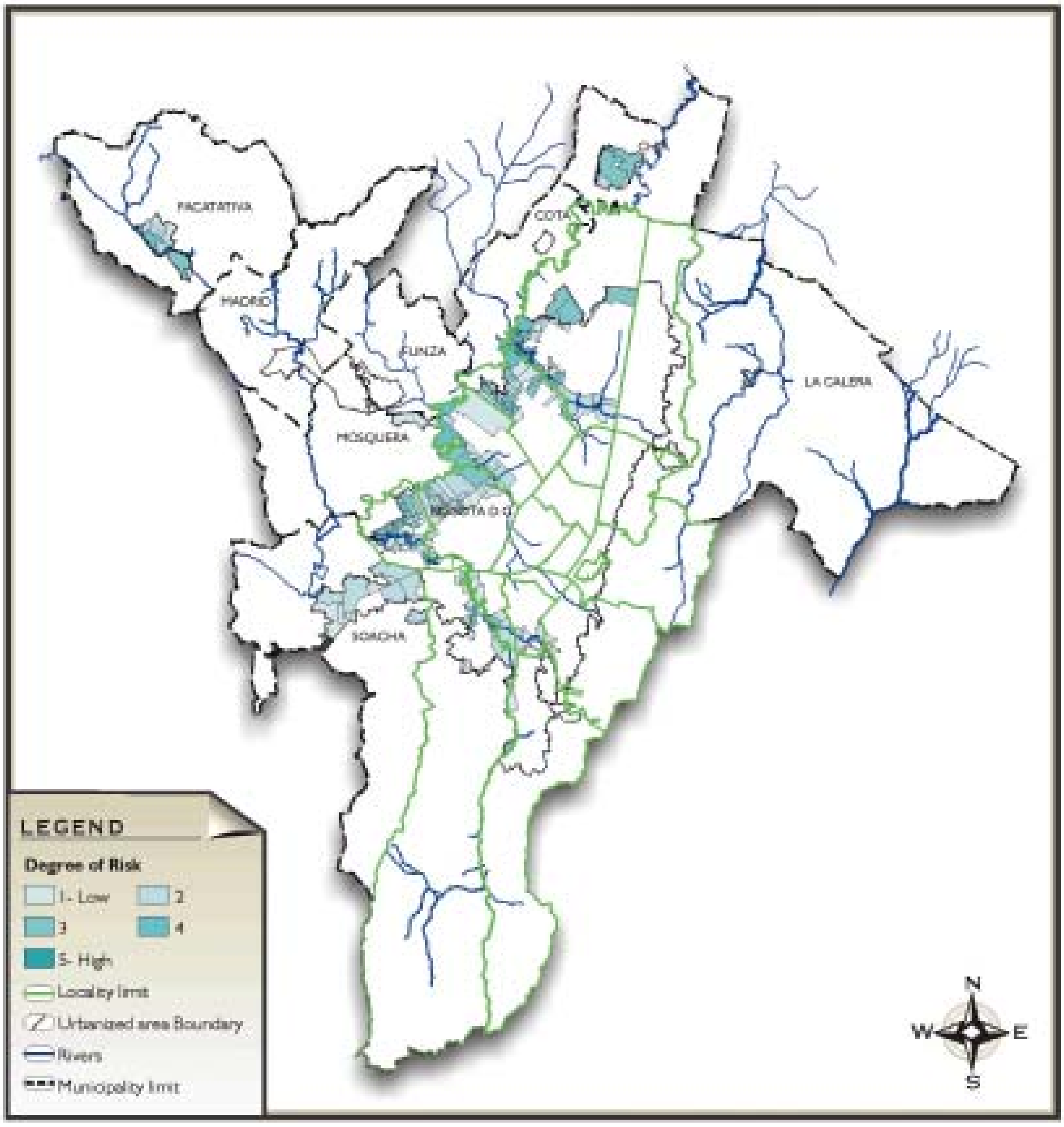


Figure 3.3.4 Degree of Regional Risk for Flood

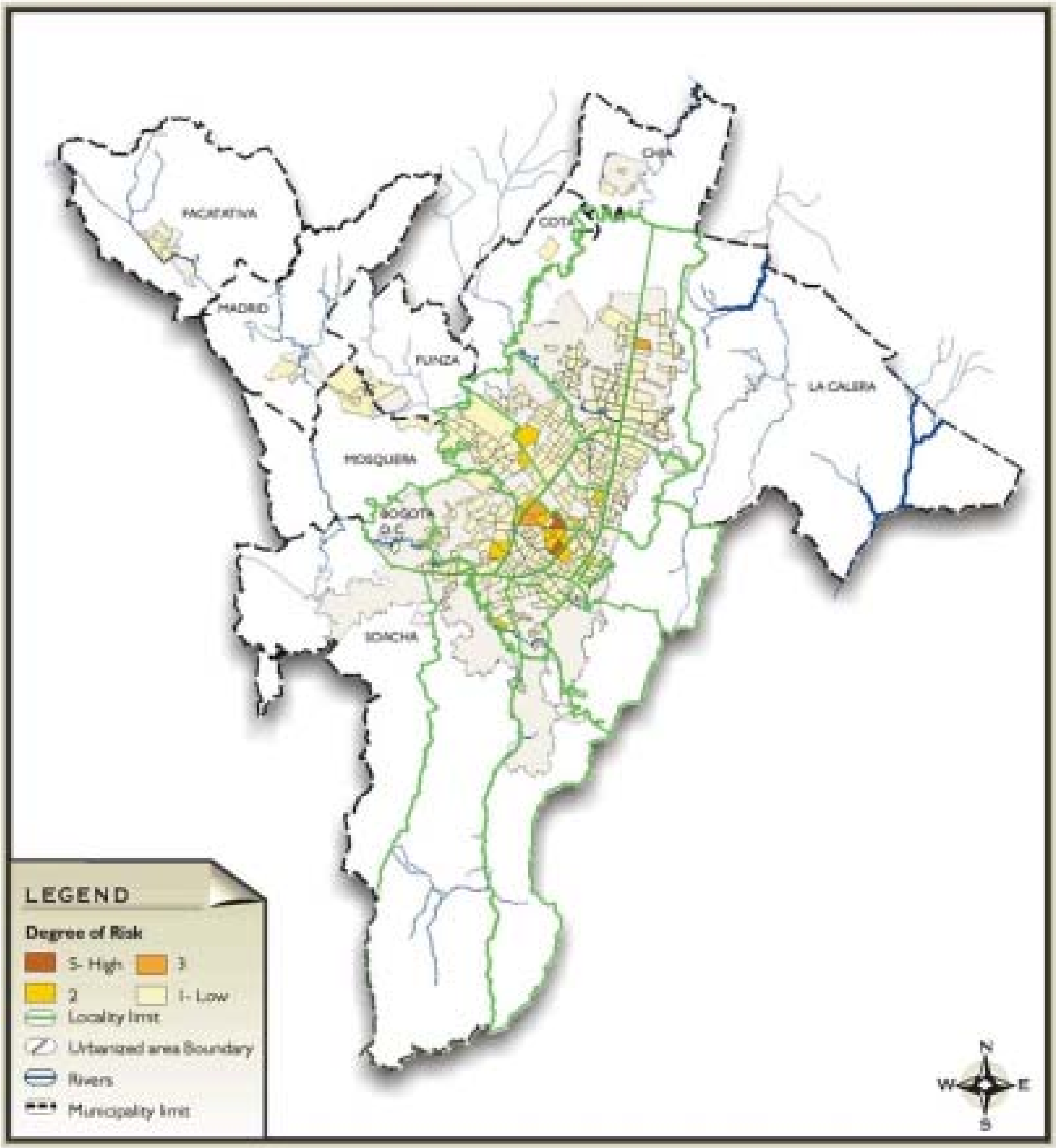


Figure 3.3.5 Degree of Regional Risk for Industrial Facilities

3.3.4 Regional Evaluation

Table 3.3.2 shows the result of regional evaluation by risk types.

1) Evaluation Criteria

The Study Team carried out regional evaluation by risk types. The criteria for the evaluation are shown as follows:

- High-Risk area: Locality including rank 4 and 5.
- Medium-Risk area: Locality including rank 3.
- Low-Risk area: Locality including rank 2 and 1.

It should be noted that the regional classification map shows the relative risks among localities in the Study Area and it could not provide a comparison among the disaster types.

For the landslide evaluation, the evaluation for the high risk area is exceptional; it is defined as follows:

- High-Risk area: Includes rank 4 and 5, and the high risk evaluated landslide points.

Table 3.3.2 Result of Regional Evaluation by Risk Types

Locality	High-Risk Area*				Evaluation	
	Earthquake	Landslide	Flood	Industry	Disaster Type	Risk Type
1. Usaquén	◎	○	-	○	Earthquake, Landslide, Industry	F
2. Chapinero	○	○	-	-	Earthquake, Landslide	B
3. Santa Fe	◎	○	-	-	Earthquake, Landslide	B
4. San Cristobal	◎	○	-	-	Earthquake, Landslide	B
5. Usme	◎	○	-	-	Earthquake, Landslide	B
6. Tunjuelito	◎	○	○	-	Earthquake, Landslide, Flood	E
7. Bosa	◎	-	◎	-	Earthquake, Flood	C
8. Kennedy	◎	-	○	-	Earthquake, Flood	C
9. Fontibón	◎	-	◎	-	Earthquake, Flood	C
10. Engativá	◎	-	◎	-	Earthquake, Flood	C
11. Suba	◎	○	◎	-	Earthquake, Landslide, Flood	E
12. Barrios Unidos	○	-	-	-	Earthquake	A
13. Teusaquillo	○	-	-	-	Earthquake	A
14. Mártires	○	-	-	-	Earthquake	A
15. Antonio Nariño	◎	-	-	-	Earthquake	A
16. Puente Aranda	◎	-	-	◎	Earthquake. Industry	D
17. La Candelaria	◎	◎	-	-	Earthquake, Landslide	B
18. Rafael Uribe	◎	○	-	-	Earthquake, Landslide	B
19. Ciudad Bolívar	◎	◎	○	-	Earthquake, Landslide, Flood	E
20. La Calera	○	-	○	-	Earthquake, Flood	C
21. Chía	◎	-	○	-	Earthquake, Flood	C
22. Cota	◎	-	◎	-	Earthquake, Flood	C
23. Facatativá	◎	○	◎	-	Earthquake, Landslide, Flood	E
24. Funza	○	-	-	-	Earthquake	A
25. Madrid	○	-	-	-	Earthquake	A
26. Mosquera	○	-	-		Earthquake	A
27. Soacha	◎	○	○	-	Earthquake, Landslide, Flood	E

Note: ◎ High-Risk Locality ○ Medium-Risk Locality

Disaster types can be categorized into six types, from type A to type F. Type A is the only entry in the singular risk disaster category; the rest is classified as multiple risk disasters. Table 3.3.3 describes the classified risk types for localities and municipalities.

Table 3.3.3 Types of Disasters

Singular Risk Types	
Type A	Earthquake
Multiple Risk Types	
Type B	Earthquake and Landslide
Type C	Earthquake and Flood
Type D	Earthquake and Industry
Type E	Earthquake, Industry and Flood
Type F	Earthquake, Landslide, and Industry

Based on this classification, the urban area of 19 localities of Bogotá city and of eight municipalities of Cundinamarca were classified as follows.

- Type A: Barrios Unidos, Teusaquillo, Mártires, Antonio Nariño, Funza, Madrid, Mosquera.
- Type B: Chapinero, Santa Fe, San Cristobal, Usme, La Candelaria, Rafael Uribe.
- Type C: Bosa, Kennedy, Fontibón, Engativá, La Calera, Chía, Cota.
- Type D: Puente Aranda.
- Type E: Tunjuelito, Suba, Ciudad Bolívar, Facatativa, Soacha.
- Type F: Usaquén.

Figure 3.3.6 describes the distribution of the risk types per area.

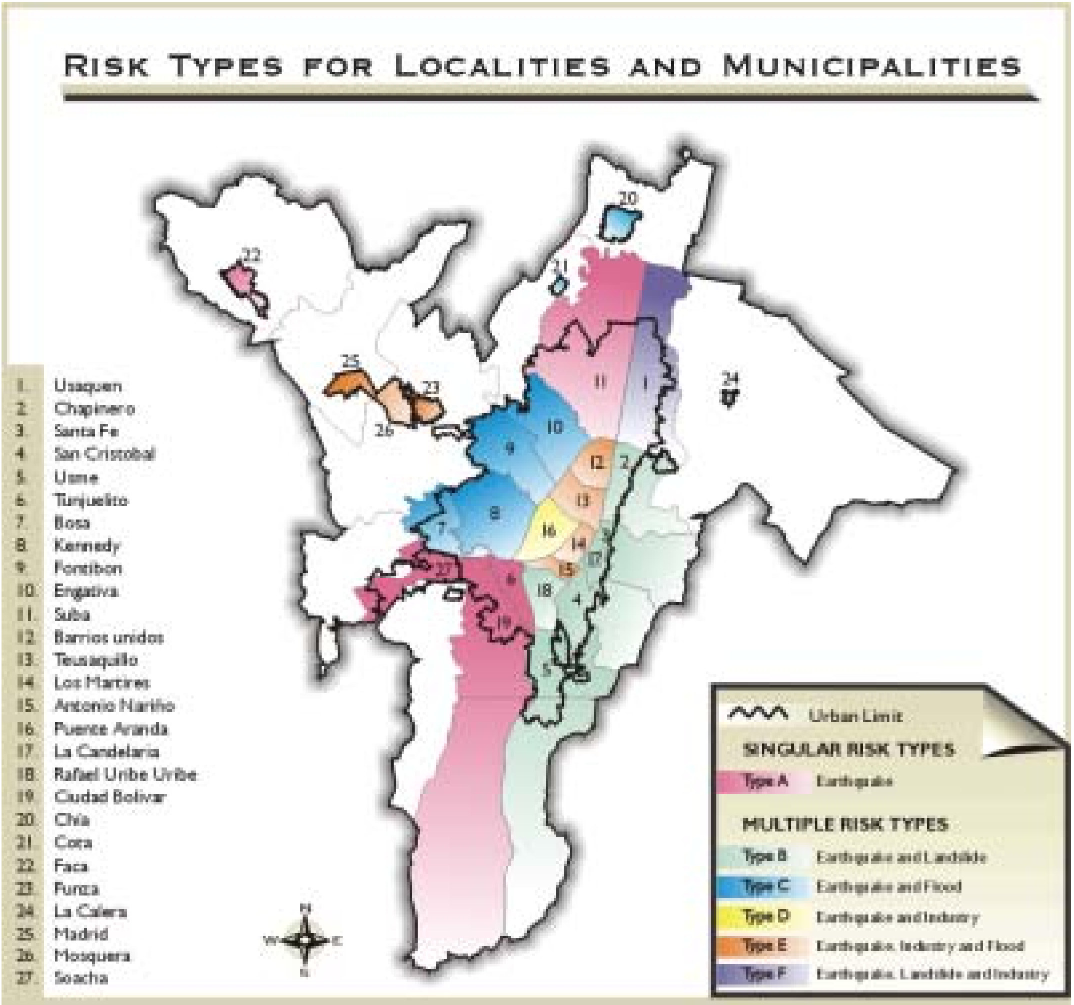


Figure 3.3.6 Distribution of the Risk Types per Area