IITR
Indian Institute of Technology Roorkee

Exploring the Earth

NORSAR ICG

Vulnerability Assessment of Hospitals and Schools in the Framework of Earthquake Risk and Loss Assessment Studies

Dominik H. Lang, Emrah Erduran
NORSAR/International Centre of Geohazards (ICG)
Kjeller, Norway

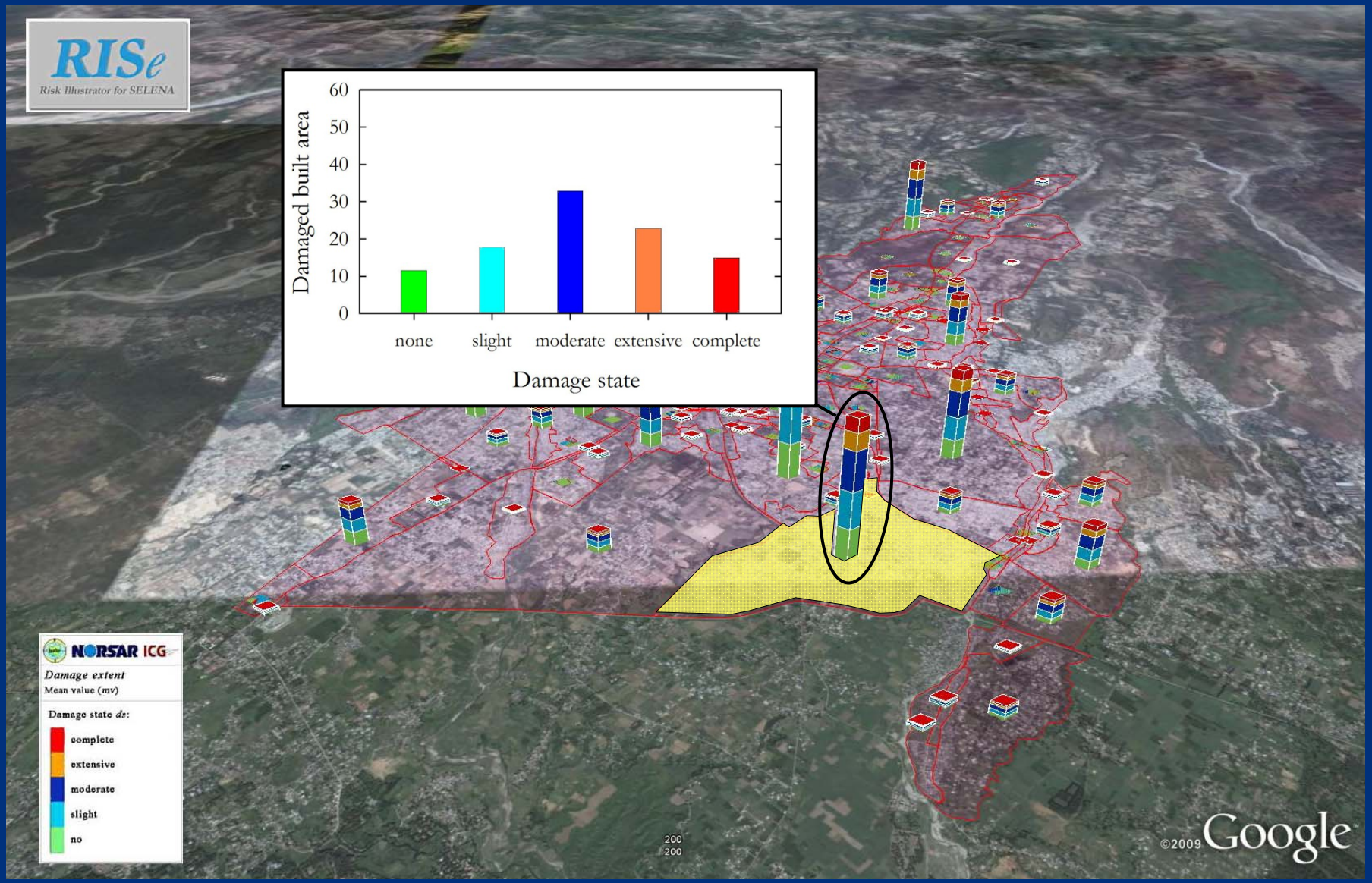
Yogendra Singh
Indian Institute of Technology Roorkee (IITR)
Roorkee, Uttarakhand, India

SERAMAR Workshop, Antakya (Hatay), Türkiye — Sept 30th – Oct 2nd, 2010

Introduction

- → Earthquake risk and loss assessment studies
  - → relative coarse spatial resolution
  - → overall damage grade (damage state)
  - → dependent on definition of building typologies / vulnerability classes

Introduction



Introduction

→ Earthquake risk and loss assessment studies

- → relative coarse spatial resolution
- → overall damage grade (damage state)
- → dependent on definition of building typologies / vulnerability classes
- → non-structural vulnerability — only seldom

  operational vulnerability/status — never accounted for

Introduction

→ Earthquake risk and loss assessment studies

- → relative coarse spatial resolution
- → overall damage grade (damage state)
- → dependent on definition of building typologies / vulnerability classes
- → non-structural vulnerability — only seldom
  operational vulnerability/status — never accounted for

both are of utmost importance in case of hospitals and schools

Introduction

→ Earthquake risk and loss assessment studies
  → relative coarse resolution
  → dependent on definition of building typologies / vulnerability classes
  → non-structural vulnerability only seldom
    operational vulnerability never accounted for

→ Seismic safety investigation of high-priority buildings
  → conventional risk and loss methodologies are not sufficient
  → pivotal structural and non-structural peculiarities that cannot be accounted for by building typology classes

  ⇒ special ways of investigation are required

! hospital and school investigations establish a good opportunity to communicate earthquake risk to public authorities and local governments

Scope and motivation

"(..) among EUROPA-MHA [*)] member states, earthquakes have only caused severe damage to a small portion of existing buildings – most were schools, some were hospitals."

Multinovic (2004)

Collapse of an undergraduate school building in Cariaco, Northeastern Venezuela (July 9, 1997)

[*)] Note: MHA - Multi-hazard Agreement

Scope and motivation

- What is it that hospitals and schools are so important in case of a disaster?
  - both are among high-priority structures
  - both are of utmost importantance in the immediate aftermath of a disaster, i.e. meeting point, organization hub, (shelter)
  - numerous peculiar structural and non-structural characteristics that affect the buildings' overall vulnerability
  - both have high occupancy rates (i.e., people per sqm)

Daytime occupancy rates (FEMA 174, 1989):

permanent dwelling	1.2 occupants per 100 m^2
government service	4.0
hospitals	**5.0 (24/7)**
fast-food restaurants	10.0
educational buildings	**20.0**

Scope and motivation: *Hospitals/health centres*

→ a high percentage of occupants are disabled/immobile

→ hazardous items and installations (oxygen or other gases, chemicals etc) lead to follow-up damages (e.g. fires, chemical burns)

→ lots of acceleration-sensitive installations (elevators, tubing, piping, suspended ceilings), which easily fail and lead to follow-up damages

→ Damage to medical equipment leads to high economical losses

→ hospital failure causes not only primary damage to the occupants, but also leads to breakdown/outfall for treating injured people (secondary damage)

e.g., Indian Ocean tsunami disaster, December 2004:

⇨ 61 % of all health facilities damaged in Northern Aceh province

⇨ 7 % of its health workers and 30 % of its midwives killed

from United Nations (2008)

Scope and motivation: *Schools*

→ numerous psychological/ethical reasons

→ children don't act like adults ⇒ high loss numbers

→ unawareness of the disproportionate levels of damage to school buildings worldwide

> e.g., United States:
>
> ⇨ never been a damaging event during school hours since 1933
>
> ⇨ death toll quite low as a considerable number of "near misses"
>
> *Tracy Monk (2007)*

→ school buildings are often ‘model projects’ of a certain era of construction ⇒ duplicating the same deficiencies to all over the country

Scope and motivation: *Model projects*

→ the use of 'model projects' for the public sector is common in Turkey, e.g.,

1. public schools

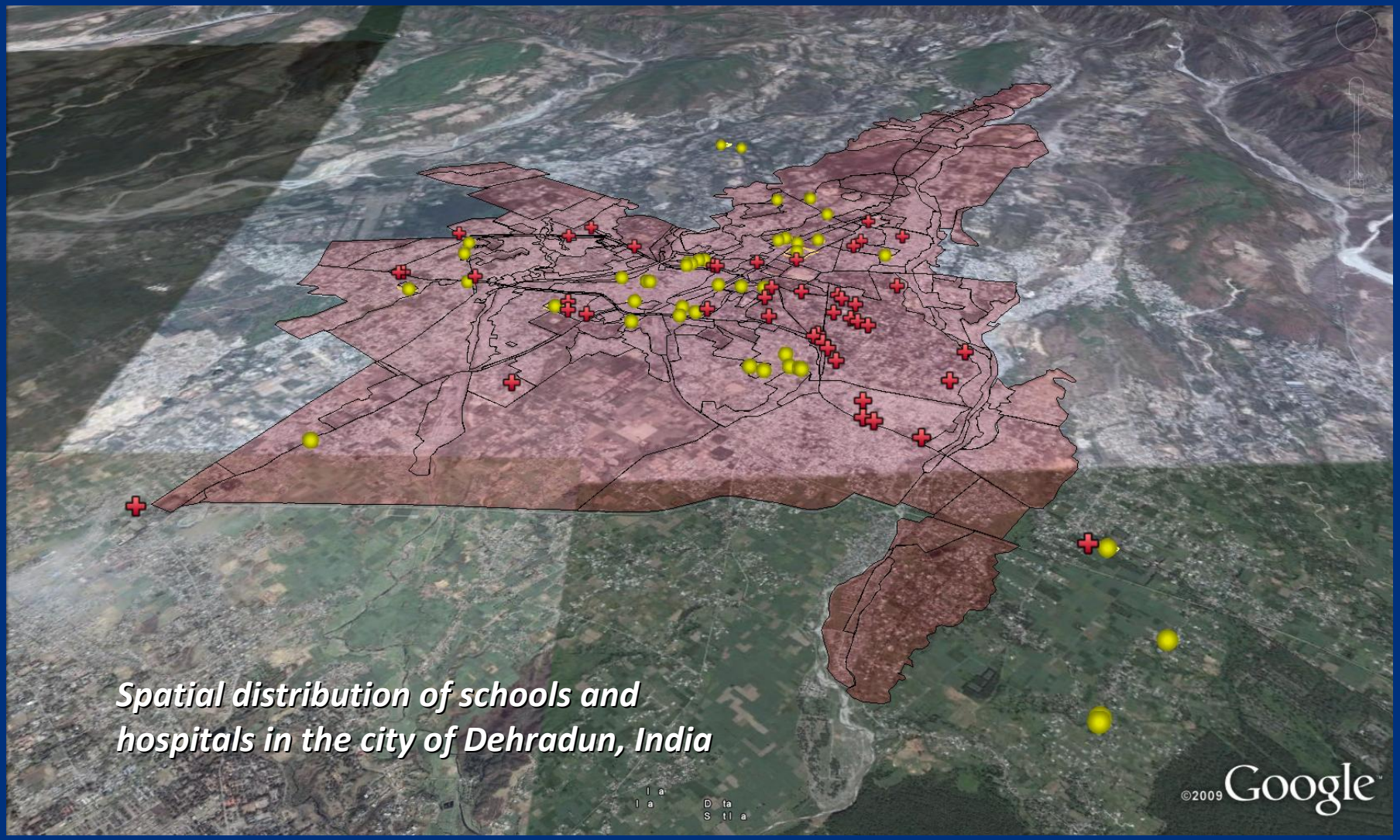
2. health centers (sağlik ocağı)

2. administration (bayindirlik müdürlüğü)

Beyhan & Gülkan (2010)

Scope and motivation

→ Which facilities require immediate attention? → generation of ‘priority list’



Spatial distribution of schools and hospitals in the city of Dehradun, India

Rapid visual screening procedures

→ detailed structural analysis of a larger number of buildings, in general, not possible; need for a rapid tool (especially in the aftermath of a disaster)

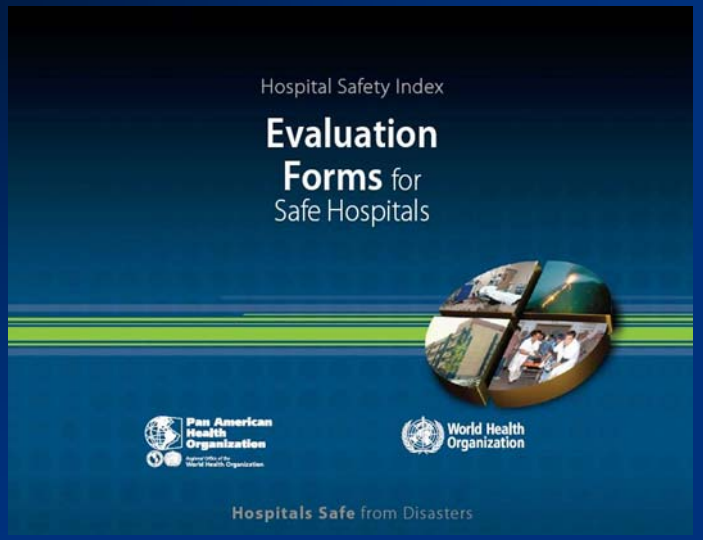
→ generation of a priority list in order to allow more targeted and more sophisticated investigation

→ a number of 'rapid sample survey procedures' exist,

e.g. rapid visual screening (RVS) procedure (FEMA 1988, 2002)

(enhanced) E-RVS procedure (Wang and Goettel, 2007)

Hospital Safety Index method (PAHO 2000, 2008)



PAHO's Hospital Safety Index method

(multi-hazard screening method for health facilities)

Quick sample survey procedure

→ following already existing procedures (e.g., PAHO, FEMA)

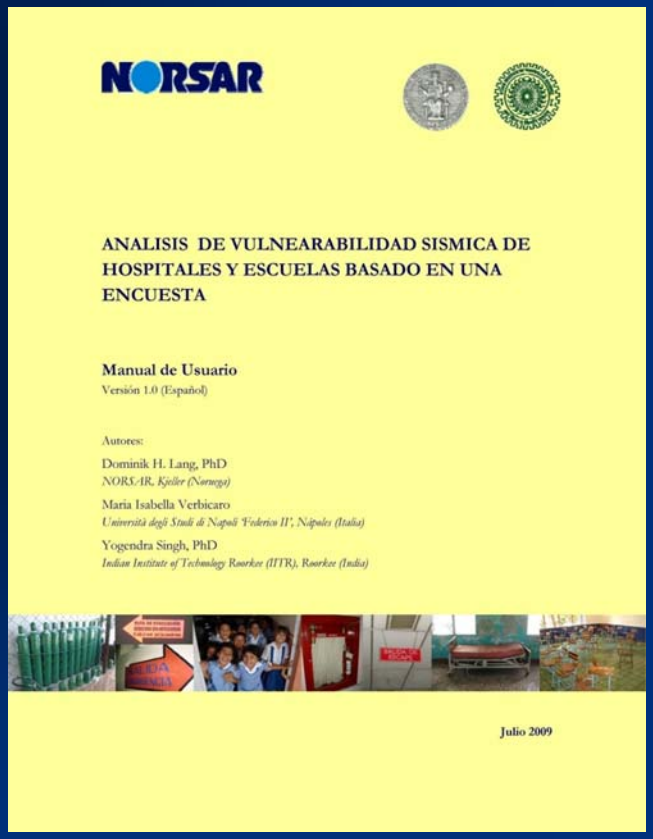
→ questionnaire survey addressing structural and non-structural vulnerability neglecting operational vulnerability

→ covers only seismic vulnerability, no multi-hazard approach

→ provided for hospitals and educational buildings → slightly different questionnaires

→ structural and non-structural vulnerability are treated separately

→ only buildings vulnerability is investigated, not geology, topography, seismic hazard etc.


NORSAR

ANALISIS DE VULNEARABILIDAD SISMICA DE HOSPITALES Y ESCUELAS BASADO EN UNA ENCUESTA

Manual de Usuario

Versión 1.0 (Español)

Autores:

Dominik H. Lang, PhD

NORSAR, Kjeller (Noruega)

Maria Isabella Verbicaro

Università degli Studi di Napoli 'Federico II', Nápoles (Italia)

Yogendra Singh, PhD

Indian Institute of Technology Roorkee (IITR), Roorkee (India)

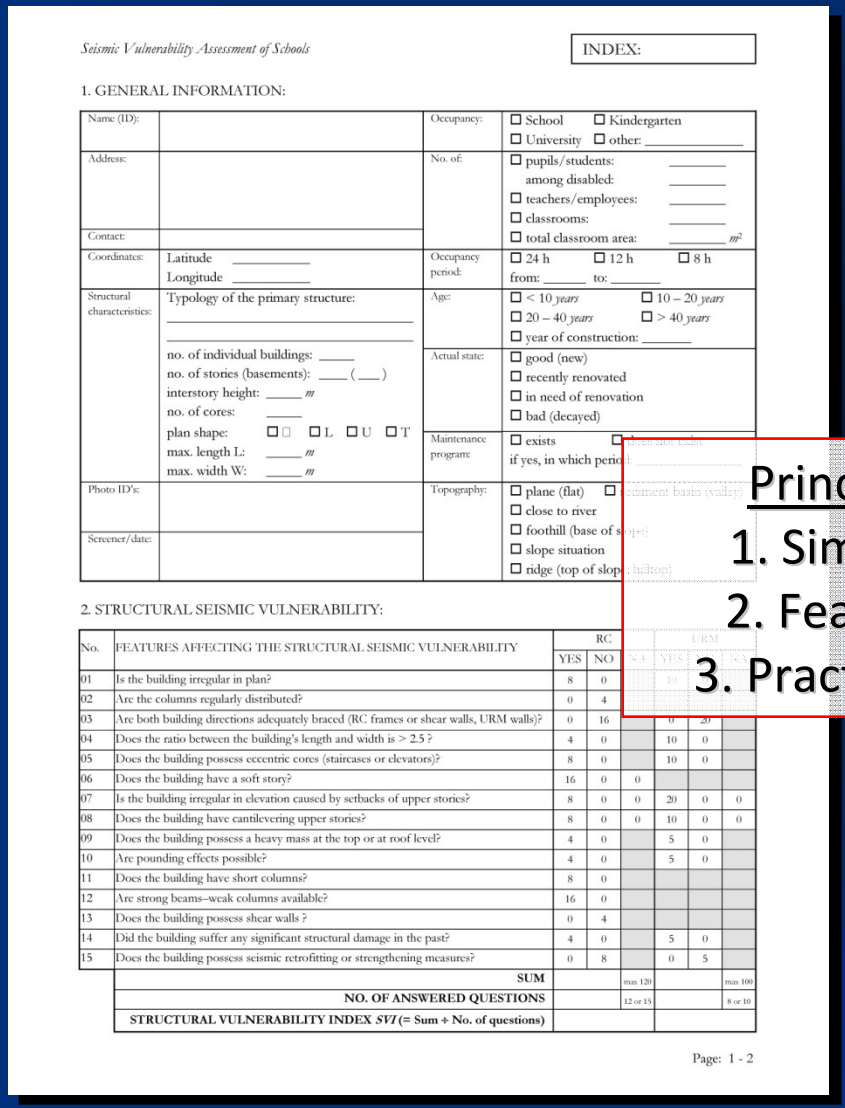
Julio 2009

Quick sample survey procedure – *Challenge*

Comparability of completely different structures

Quick sample survey procedure – *Questionnaires*

Questionnaires consist of 3 parts: *general, structural* and *non-structural part*



Seismic Vulnerability Assessment of Schools INDEX:

1. GENERAL INFORMATION:

Name (ID):		Occupancy:	☐ School ☐ Kindergarten ☐ University ☐ other: _____
Address:		No. of:	☐ pupils/students: _____ among disabled: _____ ☐ teachers/employees: _____ ☐ classrooms: _____ ☐ total classroom area: _____ m^2
Contact:			
Coordinates:	Latitude _____ Longitude _____	Occupancy period:	☐ 24 h ☐ 12 h ☐ 8 h from: _____ to: _____
Structural characteristics:	Typology of the primary structure: _____ _____ no. of individual buildings: _____ no. of stories (basements): _____ (___) interstory height: _____ *m* no. of cores: _____ plan shape: ☐ □ ☐ L ☐ U ☐ T max. length L: _____ *m* max. width W: _____ *m*	Age:	☐ < 10 *years* ☐ 10 – 20 *years* ☐ 20 – 40 *years* ☐ > 40 *years* ☐ year of construction: _____
		Actual state:	☐ good (new) ☐ recently renovated ☐ in need of renovation ☐ bad (decayed)
		Maintenance program:	☐ exists ☐ [illegible] if yes, in which peri[illegible]
Photo ID's:		Topography:	☐ plane (flat) ☐ [illegible]tment basin (valley) ☐ close to river ☐ foothill (base of slo[illegible]) ☐ slope situation ☐ ridge (top of slop[illegible], hilltop)
Screener/date:			

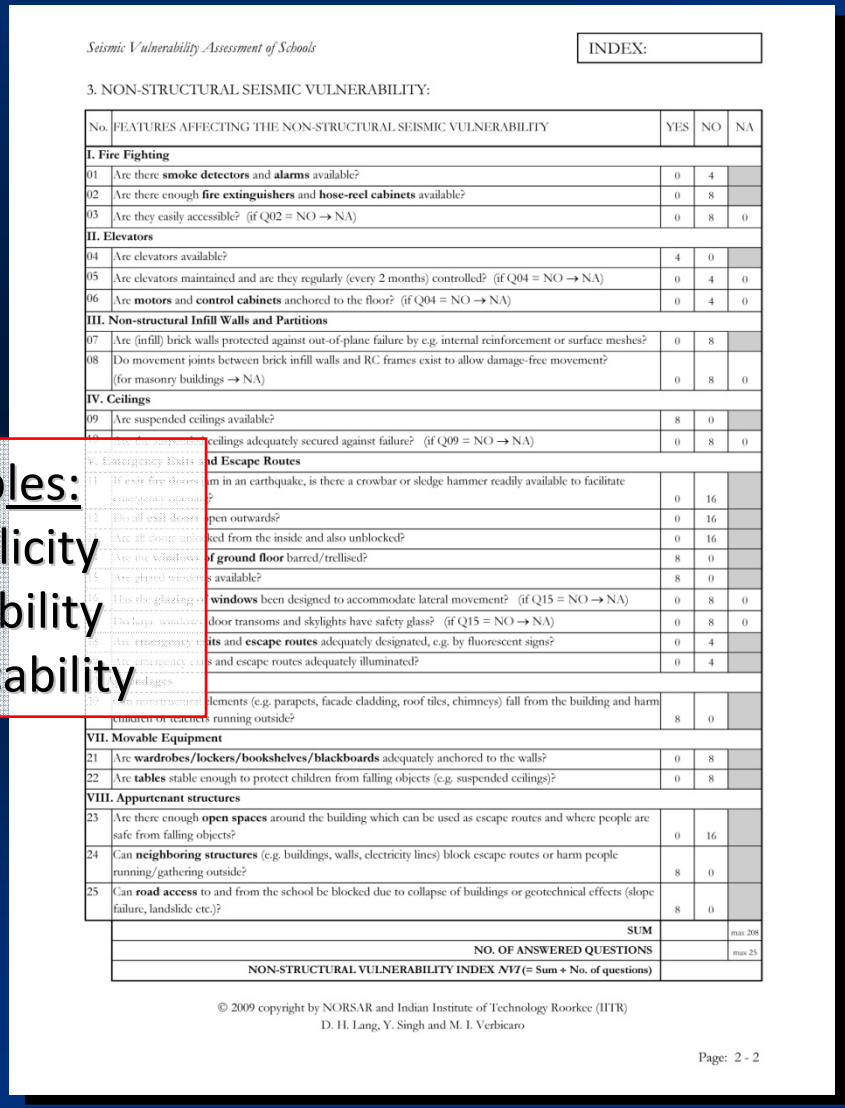
2. STRUCTURAL SEISMIC VULNERABILITY:

No.	FEATURES AFFECTING THE STRUCTURAL SEISMIC VULNERABILITY	RC			URM		
		YES	NO	NA	YES	NO	NA
01	Is the building irregular in plan?	8	0		[illegible]		
02	Are the columns regularly distributed?	0	4		[illegible]		
03	Are both building directions adequately braced (RC frames or shear walls, URM walls)?	0	16		0	20	
04	Does the ratio between the building's length and width is > 2.5 ?	4	0		10	0	
05	Does the building possess eccentric cores (staircases or elevators)?	8	0		10	0	
06	Does the building have a soft story?	16	0	0			
07	Is the building irregular in elevation caused by setbacks of upper stories?	8	0	0	20	0	0
08	Does the building have cantilevering upper stories?	8	0	0	10	0	0
09	Does the building possess a heavy mass at the top or at roof level?	4	0		5	0	
10	Are pounding effects possible?	4	0		5	0	
11	Does the building have short columns?	8	0				
12	Are strong beams–weak columns available?	16	0				
13	Does the building possess shear walls ?	0	4				
14	Did the building suffer any significant structural damage in the past?	4	0		5	0	
15	Does the building possess seismic retrofitting or strengthening measures?	0	8		0	5	
	SUM			max 120			max 100
	NO. OF ANSWERED QUESTIONS			12 or 15			8 or 10
	STRUCTURAL VULNERABILITY INDEX *SVI* (= Sum ÷ No. of questions)						

Page: 1 - 2

Principles:

1. Simplicity
2. Feasibility
3. Practicability



Seismic Vulnerability Assessment of Schools INDEX:

3. NON-STRUCTURAL SEISMIC VULNERABILITY:

No.	FEATURES AFFECTING THE NON-STRUCTURAL SEISMIC VULNERABILITY	YES	NO	NA
I. Fire Fighting				
01	Are there **smoke detectors** and **alarms** available?	0	4	
02	Are there enough **fire extinguishers** and **hose-reel cabinets** available?	0	8	
03	Are they easily accessible? (if Q02 = NO → NA)	0	8	0
II. Elevators				
04	Are elevators available?	4	0	
05	Are elevators maintained and are they regularly (every 2 months) controlled? (if Q04 = NO → NA)	0	4	0
06	Are **motors** and **control cabinets** anchored to the floor? (if Q04 = NO → NA)	0	4	0
III. Non-structural Infill Walls and Partitions				
07	Are (infill) brick walls protected against out-of-plane failure by e.g. internal reinforcement or surface meshes?	0	8	
08	Do movement joints between brick infill walls and RC frames exist to allow damage-free movement? (for masonry buildings → NA)	0	8	0
IV. Ceilings				
09	Are suspended ceilings available?	8	0	
10	Are [illegible] ceilings adequately secured against failure? (if Q09 = NO → NA)	0	8	0
V. Emergency Exits and Escape Routes				
11	If exit fire doors [illegible]m in an earthquake, is there a crowbar or sledge hammer readily available to facilitate emergency opening?	0	16	
12	Do all exit doors [illegible]pen outwards?	0	16	
13	Are all doors [illegible]ked from the inside and also unblocked?	0	16	
14	Are the windows [illegible]**f ground floor** barred/trellised?	8	0	
15	Are glazed [illegible]s available?	8	0	
16	Has the glazing [illegible]**windows** been designed to accommodate lateral movement? (if Q15 = NO → NA)	0	8	0
17	Do large windows [illegible]door transoms and skylights have safety glass? (if Q15 = NO → NA)	0	8	0
18	Are emergency [illegible]**its** and **escape routes** adequately designated, e.g. by fluorescent signs?	0	4	
19	Are emergency [illegible]s and escape routes adequately illuminated?	0	4	
	[illegible]dges			
20	Are nonstructural [illegible]lements (e.g. parapets, facade cladding, roof tiles, chimneys) fall from the building and harm children or teachers running outside?	8	0	
VII. Movable Equipment				
21	Are **wardrobes/lockers/bookshelves/blackboards** adequately anchored to the walls?	0	8	
22	Are **tables** stable enough to protect children from falling objects (e.g. suspended ceilings)?	0	8	
VIII. Appurtenant structures				
23	Are there enough **open spaces** around the building which can be used as escape routes and where people are safe from falling objects?	0	16	
24	Can **neighboring structures** (e.g. buildings, walls, electricity lines) block escape routes or harm people running/gathering outside?	8	0	
25	Can **road access** to and from the school be blocked due to collapse of buildings or geotechnical effects (slope failure, landslide etc.)?	8	0	
	SUM			max 208
	NO. OF ANSWERED QUESTIONS			max 25
	NON-STRUCTURAL VULNERABILITY INDEX *NVI* (= Sum ÷ No. of questions)			

Page: 2 - 2

Questionnaires – *Structural vulnerability*

Questions addressing structural features and their levels of importance:

No.	Question	Level of importance	
		RC	masonry
1	Is the building irregular in plan?	moderate	moderate
2	Are the columns regularly distributed?	low	*not applicable*
3	Are both building directions adequately braced?	high	High
4	Does the ratio between the building's length and width is > 2.5?	low	moderate
5	Does the building possess eccentric cores (staircases or elevators)?	moderate	moderate
6	Does the building have a soft storey?	high	*not applicable*
7	Is the building irregular in elevation caused by setbacks of upper stories?	moderate	high
8	Does the building have cantilevering upper stories?	moderate	moderate
9	Does the building possess a heavy mass at the top or at roof level?	low	low
10	Are pounding effects possible?	low	low
11	Does the building have short columns?	moderate	*not applicable*
12	Are strong beams–weak columns available?	high	*not applicable*
13	Does the building possess shear walls?	low	*not applicable*
14	Did the building suffer any significant structural damage in the past?	low	low
15	Does the building possess retrofitting or strengthening measures?	moderate	low

Results – *Structural vulnerability*

Statistical analysis of the results in Central America and India

No.	Factor affecting structural vulnerability	Hospitals		Schools	
		Central America	India	Central America	India
1	irregularity in plan	37	67	13	44
2	irregularly distributed columns	5	46	0	30
3	inadequately braced building directions	11	92	13	93
4	L/W ratio > 2.5	37	26	75	60
5	eccentric cores	26	72	38	55
6	soft storey	5	17	0	20
7	irregularity in elevation caused by setbacks	22	28	0	7
8	cantilevering upper stories	7	13	50	2
9	heavy mass at the top or at roof level	4	36	0	0
10	pounding effects possible	26	18	25	13
11	short columns	76	46	100	70
12	strong beams–weak columns	19	75	17	80
13	no shear walls	81	100	83	100
14	structural damage in the past	26	23	38	40
15	no retrofitting/strengthening	93	97	100	95

Questionnaires – *Non-structural vulnerability*

Questions addressing non-structural features and their levels of importance:

No.	Category	Components	Level of importance	
			Hospital (H)	School (S)
1	Electrical facilities	emergency generator, fuel tank, service lines and pipes, bus ducts and cables	18 %	*not applied*
2	Fire fighting	smoke detectors, alarms, fire extinguishers, hose-reel cabinets, (H: emergency water tank)	10 %	6 %
3	Propane or other gas (e.g., oxygen) pipes	shut-off valve, wrench tool, pipe installations	18 %	*not applied*
4	Elevators	maintenance, motors, control cabinets	3 %	6 %
5	Non-structural infill walls and partitions	protection of infill brick walls against out-of-plane failure, movement joints available	5 %	8 %
6	Ceilings	securing of suspended ceilings	2 %	8 %
7	Emergency exits and escape routes	exit doors, automatic doors, glazing of windows, safety glass, designation and illumination of escape routes	25 %	44 %
8	Appendages	parapets, façade cladding, roof tiles, chimneys, external AC machines	2 %	4 %
9	Movable equipment	H: gas cylinders, chemicals, hazardous materials S: wardrobes, lockers, bookshelves, blackboards, desks	6 %	8 %
10	Appurtenant structures	open spaces, neighboring structures, road access	9 %	16 %

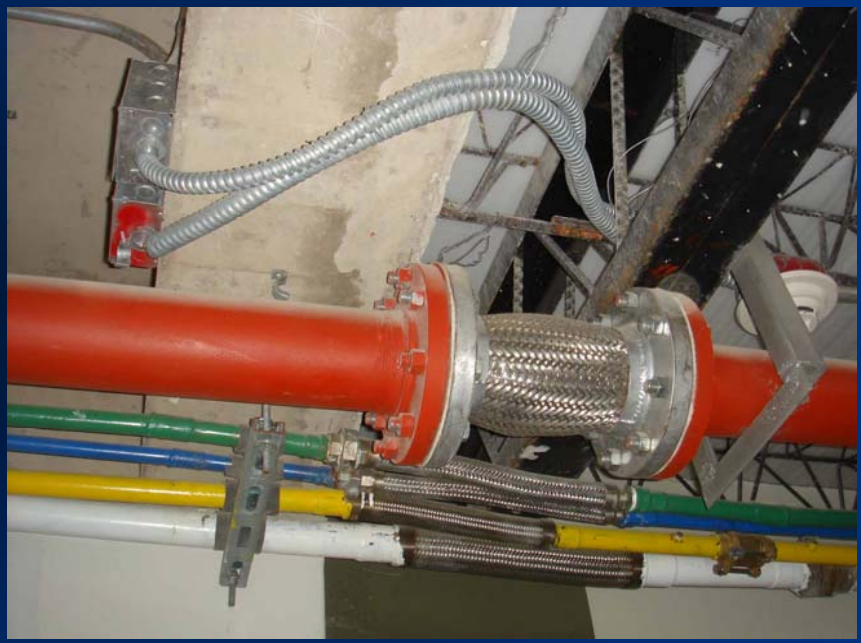
Questionnaires – *Non-structural vulnerability*

Qu.: Are all doors unlocked from the inside and also unblocked ?

Questionnaires – *Non-structural vulnerability*

Qu.: Are service lines and other pipes attached with flexible connections ?

Rigid coupling of pipes



Flexible connection of pipes

Questionnaires – *Non-structural vulnerability*

Qu.: Are gas cylinders tightly secured with chains at top and bottom ?

Questionnaires – *Non-structural vulnerability*

Qu.: Can nonstructural elements fall from the building and harm people running outside ?

Questionnaires – *Non-structural vulnerability*

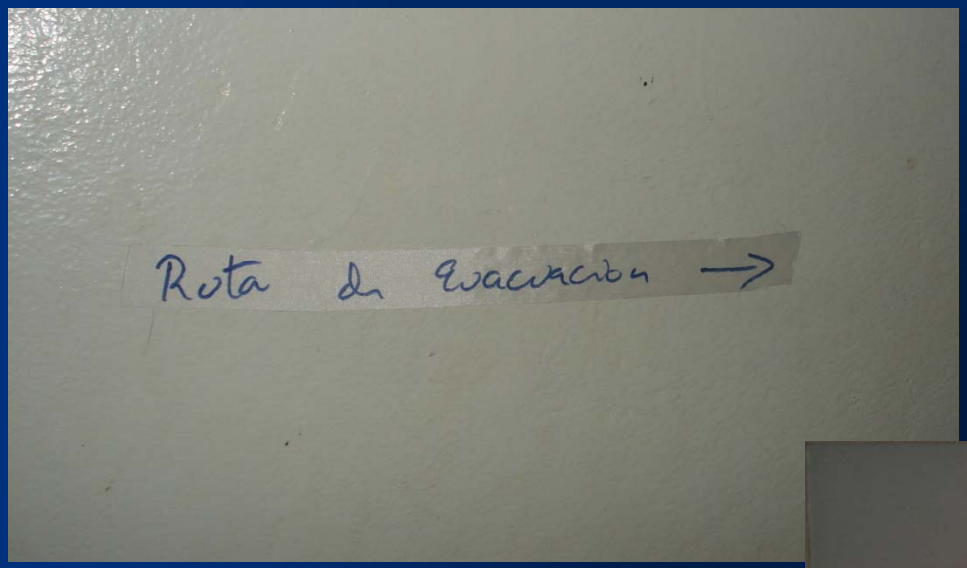
Qu.: Are there enough open spaces around the building which can be used as escape routes and where people are safe from falling objects ?

Questionnaires – *Non-structural vulnerability*

Qu.: Can neighboring structures (e.g. buildings, walls, electricity lines) block escape routes or harm pupils running/gathering outside ?

Questionnaires – *Non-structural vulnerability*

Qu.: Are emergency exits and escape routes adequately designated, e.g. by fluorescent signs?



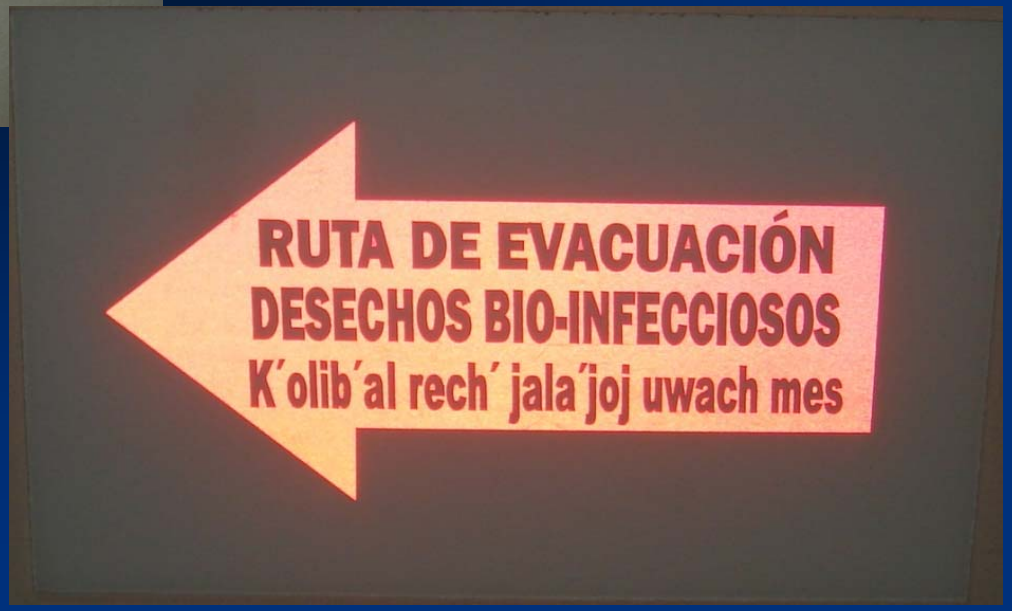
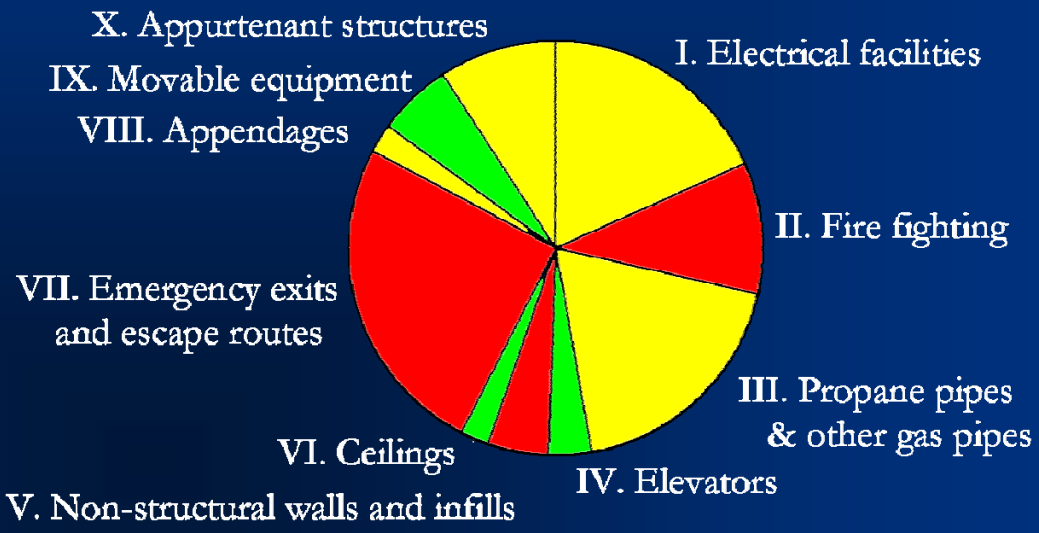


Illustration – *Non-structural vulnerability*

Visualization of non-structural results:

Hospitals:



Schools:

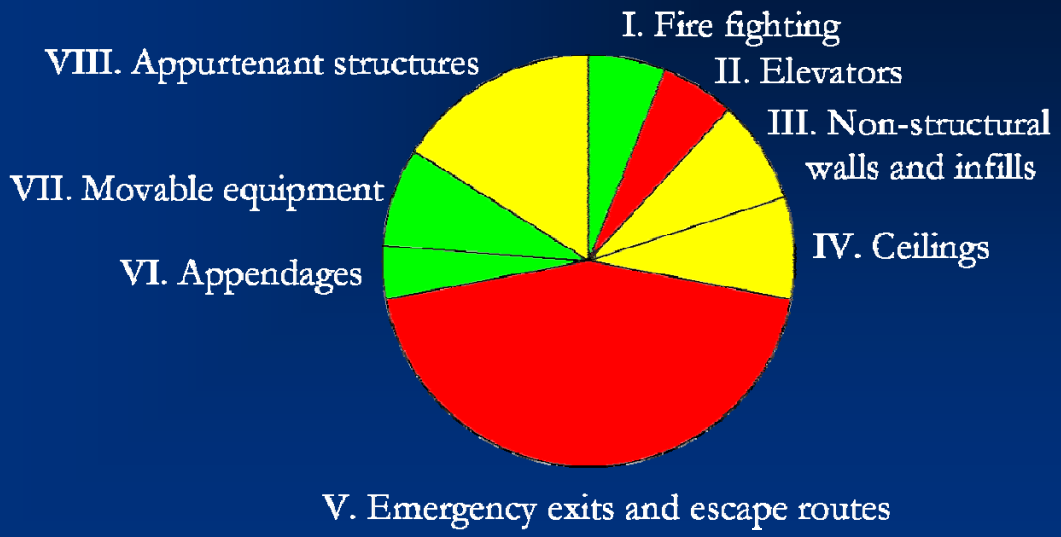


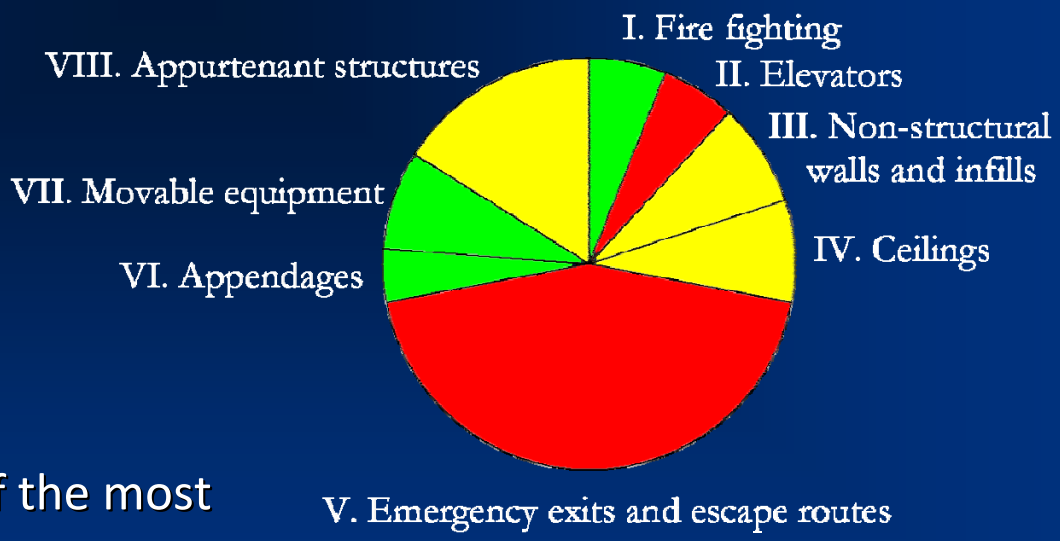
Illustration – *Non-structural vulnerability*

Visualization of non-structural results:

→ size of each piece indicates the importance of the respective category

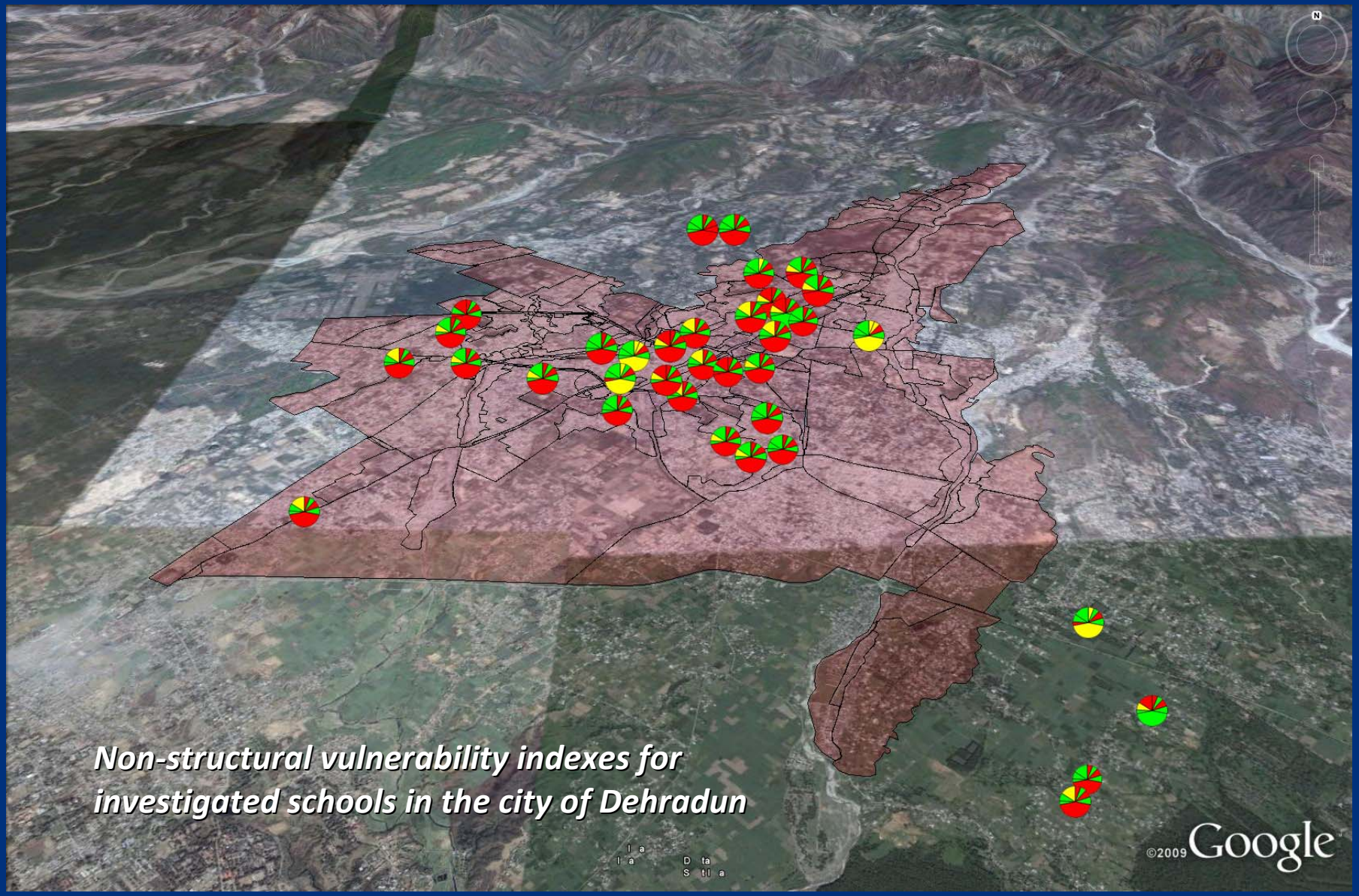
→ color code of each piece indicates the share of vulnerability points on maximum available points:

- - less than 33 %
- - between 33 and 66 %
- - more than 66 %



→ rapid and easy illustration of the most "vulnerable" structures

Visualization of results



Non-structural vulnerability indexes for investigated schools in the city of Dehradun

Results dissemination and implementation

→ strike a balance between too technically advanced and too plain

→ use language: all dissemination material should be prepared in local language using understandable terms

→ use and involve the media

→ preparation of PR material

- to inform the public and build awareness about the project and its initial purpose
- to reach as many people as possible

→ preparation of technical material that can be directly used and understood (e.g., manuals, tutorials, handbooks, procedures)

→ define short-, mid- and long-term goals

What can/should be done now? What should be done in future?

Download and contact

http://www.eqrisk.info/
http://www.norsar.no/
http://selena.sourceforge.net/

dominik@norsar.no