A Simulation Model for Forecasting Urban Vulnerability to Earthquake Disaster in Lima, Peru
LIMA-UVEQ
Toward Earthquake Resilient City

Group 5/2014.3.6
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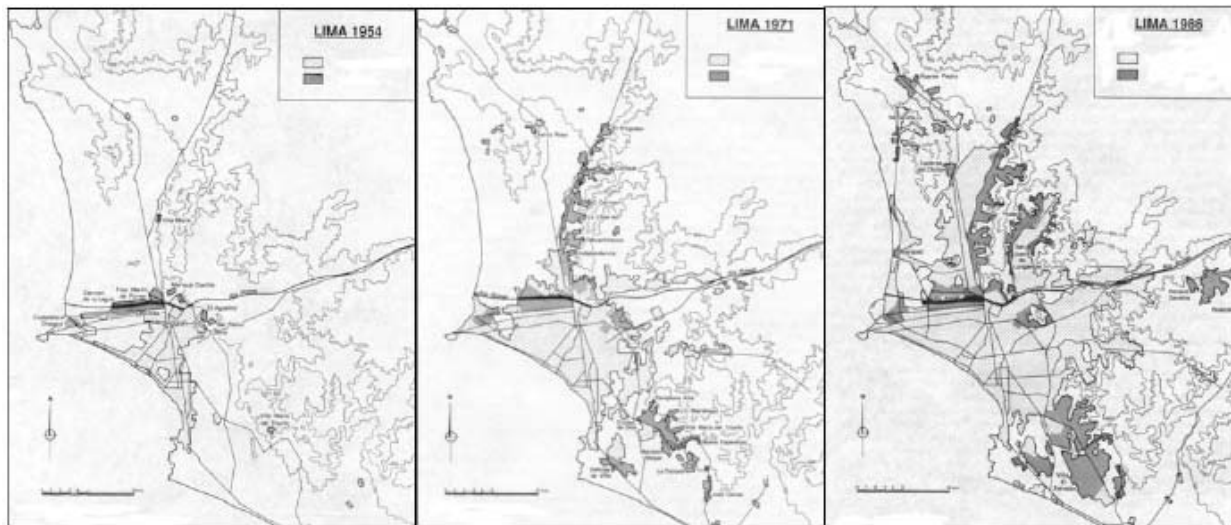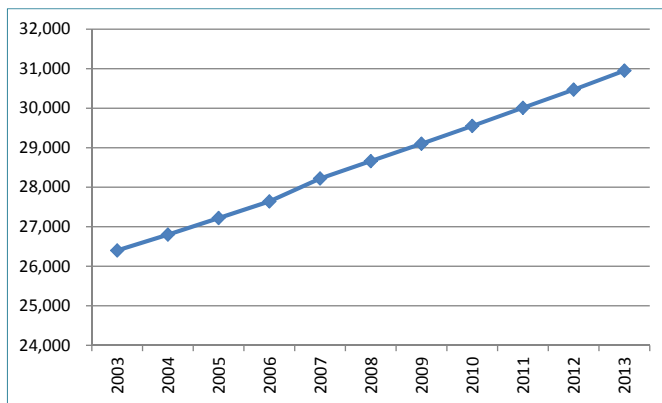## Back Ground : Expansion of Lima Metropolitan Area

Figure 2. Lima and its barriadas in 1954, 1971 and 1986. (Source: Driant, 1991)

Population Growth of Peru

year	Population	year	Population
2011	8,650,219	2021	10,544,568
2012	8,823,223	2022	10,755,459
2013	8,999,689	2023	10,970,568
2014	9,179,682	2024	11,189,998
2015	9,363,275	2025	11,413,778
2016	9,550,541	2026	11,642,053
2017	9,741,551	2027	11,874,894
2018	9,936,382	2028	12,112,391
2019	10,135,110	2029	12,354,638
2020	10,337,812	2030	12,601,730

Natural Increase Ratio = 1.611 %
(Average of recent 10 years except the year 2006)

Population of Lima Metropolitan Region = 8,480,607
 Increase Ratio = 2 %   (As of 2010)
http://www.lima-water.de/en/lima.html

Social Increase Ratio of Lima Metropolitan Region
  = 2.000 – 1.611 = 0.389 %

Total Number of Population to be
Increased by year 2030 = 4,121 Th

Purpose of Simulation Model Building

- Looking ahead ten or twenty years, the urban population will inevitably increase in the Lima Metropolitan Area.
- Thus, varieties of urban development projects will naturally be implemented in order to accommodate these additional population increments, resulting in increase of vulnerability to disaster/earthquake if no actions are taken.
- A Computer Simulation Model – LIMA UVEQ – has been developed aiming to forecast a deference of vulnerability to earthquake disasters in Lima Metropolitan Area after twenty years between two cases where some earthquake damage mitigation measures would be incorporated with urban development projects and where no such measures would be taken into account.
- The model, then, tries to propose desirable policy mix to be implemented in line with urban growth.

Policy Valuables and Target Indicators

- **Policies**
  - X1. Building code (XBC)
    - XBC=0.6: Successful practice (60% of new buildings are earthquake- resistant)
    - XBC=0.2: Insufficient practice (only 20% of new buildings are earthquake-resistant)
  - X2. Land use regulation / development prohibition (XLU)
    - XLU = 0: Perfect prohibition,
    - XLU=0.5: Half prohibition
    - XLU=1.0: No prohibition policy:
- **Events**
  - X3: Earthquake case/ EQ(t)=1 or 0 in year (t)
    - Human Damage = 1%, Evacuation ratio from Lima =10%
    - Building Damage Safe Building = 0.1%, Vulnerable Building = 2%
- **Target indicators**
  - A. IB(i,t)=BLV(i,t)/BL(i,t): Non earthquake-resistant building ratio
  - B. IP(i,t)=PPV(i,t)/PP(i,t): Ratio of population living at vulnerable area

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Policy alternatives to be tested

Possible policy alternatives are:

XLU↓ XBC→	Successful Practice XBC = 0.6	Insufficient Practice XBC = 0.2
Perfect Prohibition: 0	P1	P4
Half Prohibition: 0.5	P2	P5
No Prohibition: 1.0	P3	P6

This presentation focuses on the comparison of P1 and P6 on condition that no earthquake occurs and an earthquake occurs during said 20 years.

Earthquake↓ Policy→	P1	P6
No earthquake	Case 1	Case 2
Earthquake occurs	Case 3	Case 4

Structure of the Model: LIMA-UVEQ

A Simulation Model for Forecasting Urban Vulnerability to Earthquake Disaster in Lima, Peru :

Attractiveness Index for Location:
- Vacant Land
- Accessibility
- Maturity
- Land Price
- Public Services

Flow Diagram of LIMA-UVEQ

- ◯ Whole City Block
- ◯ Land Use Block
- ◯ Vacant Land Block
- ◯ Population Block
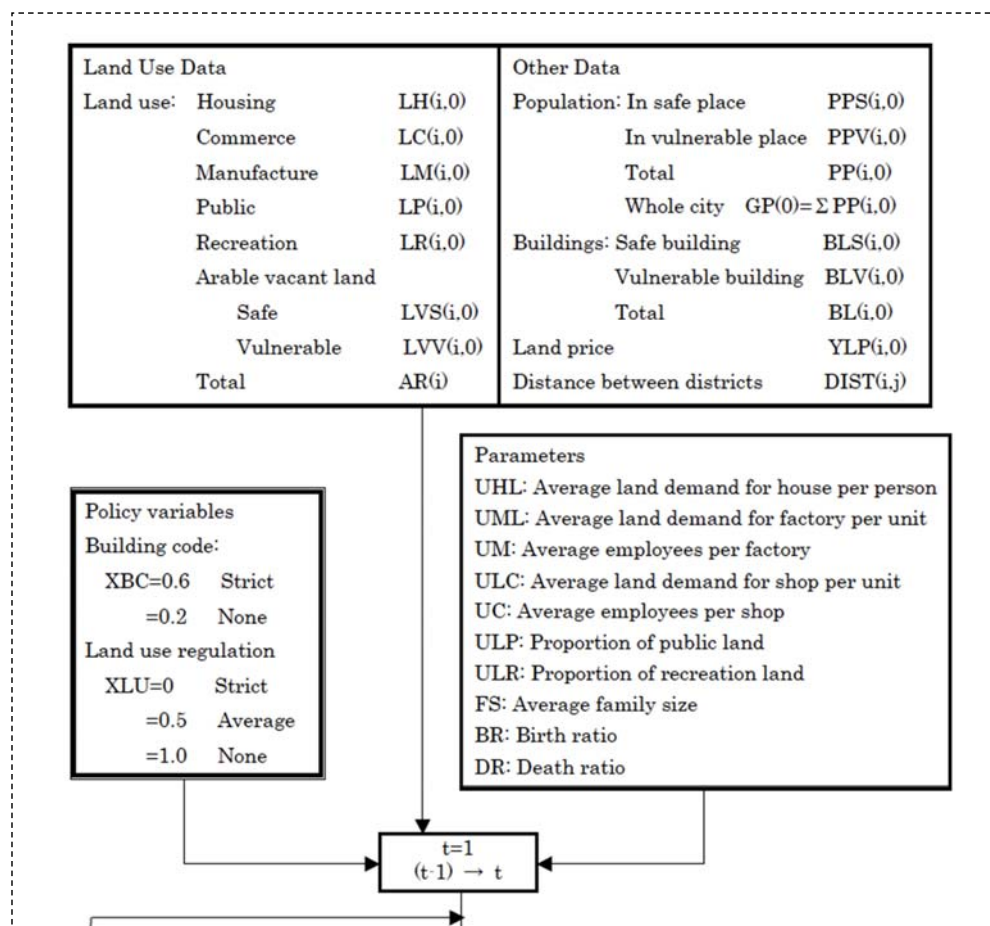- ◯ Building Block
- ▱ Policy Valuable

30 Zones

43 and 6 districts in Lima and Callao Provinces respectively are integrated into 30 zones for the sake of Computer Operation.


LIMA-UVEQ

Parameters for Simulation

Land Use Data		
Land use:	Housing	LH(i,0)
	Commerce	LC(i,0)
	Manufacture	LM(i,0)
	Public	LP(i,0)
	Recreation	LR(i,0)
	Arable vacant land	
	Safe	LVS(i,0)
	Vulnerable	LVV(i,0)
	Total	AR(i)

Other Data		
Population:	In safe place	PPS(i,0)
	In vulnerable place	PPV(i,0)
	Total	PP(i,0)
	Whole city	$GP(0) = \Sigma\, PP(i,0)$
Buildings:	Safe building	BLS(i,0)
	Vulnerable building	BLV(i,0)
	Total	BL(i,0)
Land price		YLP(i,0)
Distance between districts		DIST(i,j)

Policy variables

Building code:
- XBC=0.6   Strict
- =0.2   None

Land use regulation
- XLU=0   Strict
- =0.5   Average
- =1.0   None

Parameters

UHL: Average land demand for house per person
UML: Average land demand for factory per unit
UM: Average employees per factory
ULC: Average land demand for shop per unit
UC: Average employees per shop
ULP: Proportion of public land
ULR: Proportion of recreation land
FS: Average family size
BR: Birth ratio
DR: Death ratio

$$t=1$$
$$(t-1) \rightarrow t$$

Areas in terms of land use

Calculated by Photoshop
based on
the metropolitan map
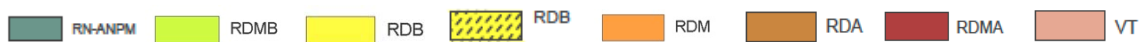
From National Institute of Statistics,
Metropolitan Lima
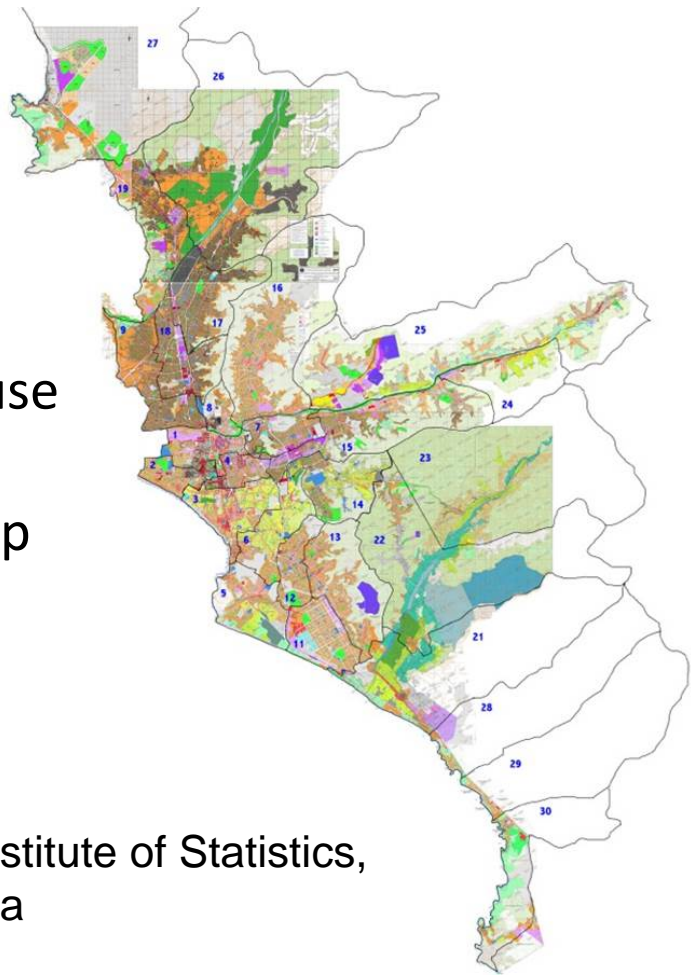
Land Use Data Used
Institute Metropolitano De Planificacion

IMP INSTITUTO METROPOLITANO DE PLANIFICACION

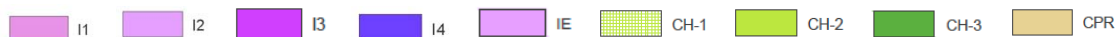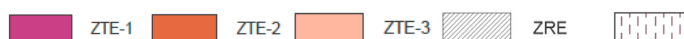Planos De Zonificacion De Lima Metropolitana Y Ordenanza De Aprobacion

- Zonas Residenciales

RN-ANPM | RDMB | RDB | RDB | RDM | RDA | RDMA | VT

- Zonas Comerciales

CV | CZ | CM

- Zonas Industriales

I1 | I2 | I3 | I4 | IE | CH-1 | CH-2 | CH-3 | CPR

- Zonas De Equipamiento y Recreacion

E1 E2 E3 E4 | ntl | H1 H2 H3 | ist | ZHR | D | ZTE | a | S | ZRP | RT | ZRP-p | · · ·

ZTE-1 | ZTE-2 | ZTE-3 | ZRE

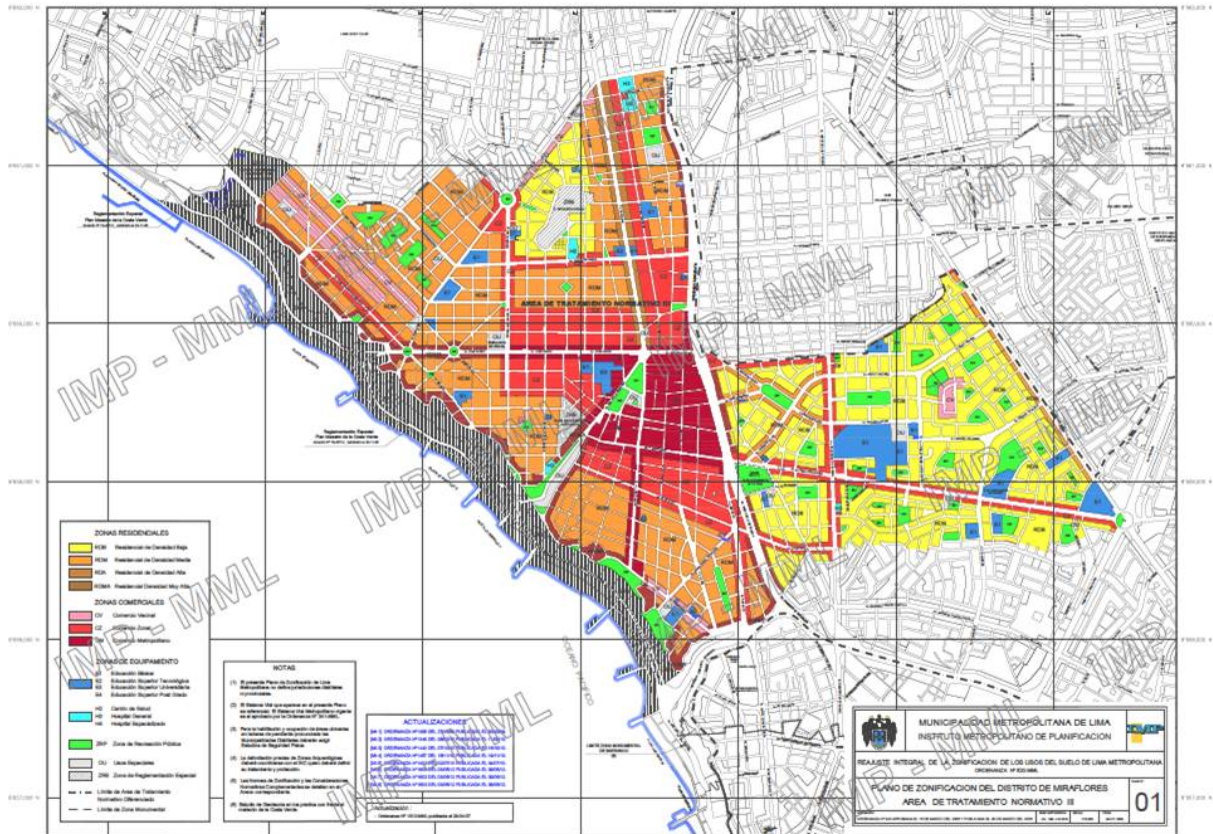(http://www.munlima.gob.pe/imp/zonificacion.html)

MIRAFLORES

ZONAS DE EQUIPAMIENTO
Zona de Recreacion Publica

ZRP

1. Extract each zone from the PDF map file

2. Calculation by "measurement feature" function in Photoshop
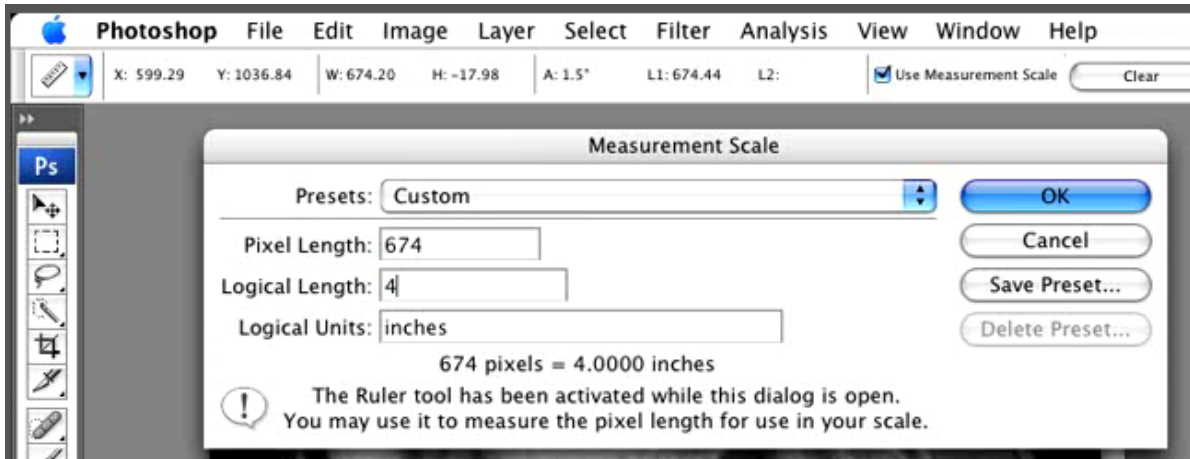
Arranged data for simulation

Province	Name	District			Zone			data
		Code	Population (persons)	Area (km²)	No	Pop	Area	
Lima (01)	Lima	101	299,493	21.98	1	381,402	25.20	○
	Brena	105	81,909	3.22				△
	Jesus Mari	113	66,171	4.57	2	320,191	23.28	△
	Puebio Lib	121	74,164	4.38				○
	Magdalena	120	50,749	3.61				○
	San Miguel	136	129,107	10.72				○
	Barranco	104	33,903	3.33	3	371,383	37.47	○
	Miraflores	122	85,065	9.62				○
	San Isidro	131	58,056	11.10				○
	San Borja	130	105,076	9.96				○
	Surquillo	141	89,283	3.46				○
	La Victoria	115	192,724	8.74	4	302,600	15.26	○
	Lince	116	55,242	3.03				○
	San Luis	134	54,634	3.49				○
	Chorrillos	108	286,977	38.94	5	286,977	38.94	○
	Santiago d	140	289,597	34.75	6	289,597	34.75	○
	El Agustino	111	180,262	12.54	7	364,876	23.23	○
	Santa Anit	137	184,614	10.69				○
	Rimac	128	176,169	11.87	8	176,169	11.87	ther Regions Inc
	San Martin	135	579,561	36.91	9	579,561	36.91	○

Result-1/Population Increase by2030

	Main District	Base Year (PP)	NEQ			EQ			
			P1 XBC=0.6 XLU=0	P6 XBC=0.2 XLU=1.0	P6-P1	P1 XBC=0.6 XLU=0	P1 EQ-NEQ	P6 XBC=0.2 XLU=1.0	P6 EQ-NEQ
1	Lima	381402	106,921	112,771	5,849	58,748	-48,173	67,631	-45,140
2	San Miguel	320191	113,378	116,303	2,924	78,479	-34,900	81,499	-34,803
3	Miraflores	371383	129,478	134,499	5,021	92,072	-37,406	97,354	-37,145
4	La Victoria	302600	89,837	90,227	390	49,440	-40,397	49,827	-40,399
5	Chorrillos	286977	99,011	119,239	20,228	74,622	-24,388	106,092	-13,147
6	Santiago de Surco	289597	104,075	121,726	17,651	83,307	-20,768	107,362	-14,365
7	Santa Anita	364876	103,161	117,914	14,753	62,092	-41,069	85,613	-32,302
8	Rimac	176169	53,680	60,945	7,265	34,600	-19,079	46,146	-14,799
9	San Martin de Porres	579561	174,646	180,922	6,276	102,585	-72,060	108,945	-71,977
10	Callao	598980	156,844	180,044	23,201	87,972	-68,872	127,910	-52,134
11	Villa El Salvador	381790	134,526	137,215	2,689	92,741	-41,785	95,876	-41,338
12	San Juan de Miraflores	362643	147,410	151,805	4,395	119,055	-28,355	123,994	-27,811
13	Villa Maria del Triunfo	378470	128,147	134,178	6,031	86,326	-41,821	95,113	-39,065
14	La Molina	132498	79,321	84,131	4,810	83,918	4,598	90,644	6,513
15	Ate	478278	178,457	184,250	5,792	135,349	-43,109	144,603	-39,646
16	San Juan de Luriganch	898448	444,870	432,064	-12,806	413,868	-31,002	381,725	-50,338
17	Comas	486977	205,404	211,892	6,487	168,256	-37,149	177,616	-34,276
18	Independencia	523787	151,148	156,269	5,121	85,711	-65,437	92,092	-64,177
19	Puente Piedra	233602	116,069	119,608	3,539	106,054	-10,015	111,780	-7,829
20	Ventanilla/Callao	277895	170,066	161,006	-9,059	177,733	7,667	162,274	1,268
21	Lurin	62940	101,650	90,039	-11,611	148,618	46,968	132,878	42,839
22	Pachacamac	68441	608,808	383,599	-225,209	979,970	371,162	617,707	234,108
23	Cieneguilla	26725	154,210	95,222	-58,989	231,372	77,161	144,426	49,204
24	Chaclacayo	41110	24,204	22,001	-2,204	23,899	-306	21,216	-785
25	Lurigancho	169359	152,666	132,345	-20,321	183,275	30,609	155,727	23,383
26	Carabayllo	213386	303,807	306,203	2,396	415,225	111,419	429,846	123,643
27	Ancon	44270	80,335	264,042	183,707	114,222	33,887	414,199	150,157
28	Punta Hermosa	5762	2,094	7,457	5,363	1,928	-166	11,201	3,745
29	Punta Nrgra	5284	2532	2,312	-220	2,371	-161	2,012	-300
30	Pucusana	17206	17654	17,295	-359	24,082	6,428	23,351	6,056
	Total	8480607	4,334,408	4,327,519		4,317,892		4,306,660	

🟢 P6-P1>5,000 persons
Population with strict land use regulation is less than that without the regulation.

🟣 P6-P1<0
Population with strict land use regulation is more than that without the regulation.
⇒Strict land use regulation restrain population growth in central parts and disperse it to the suburban areas.

◯ Earthquake decreases population of the central part and generates new urban areas in the eastern and northern districts.
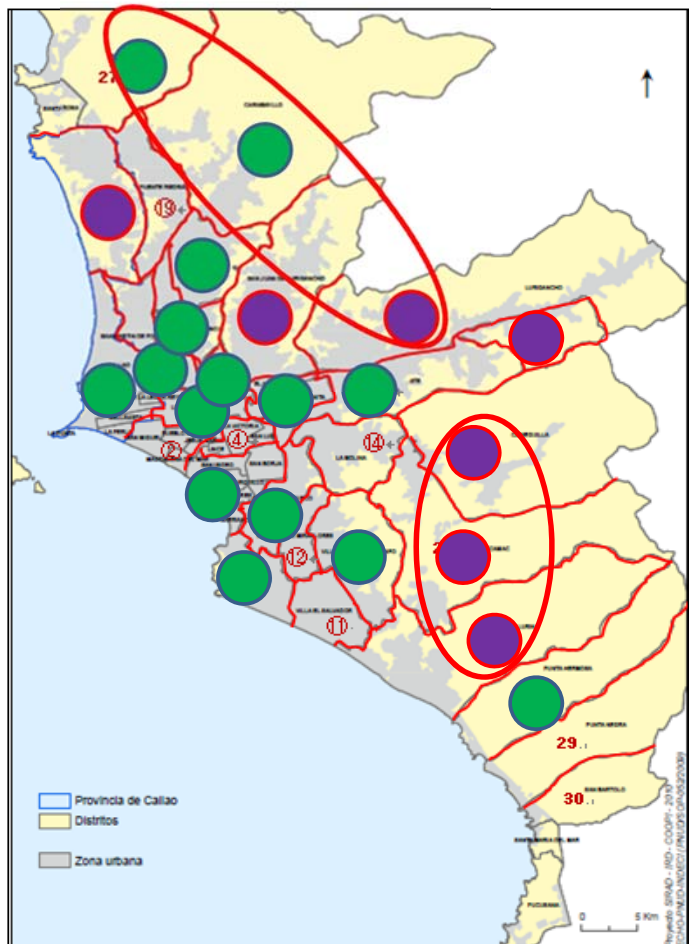
Result-2/Vulnerable Building Ratio

	Main District	Base Year (IB)	NEQ			EQ			
			P1 XBC=0.6 XLU=0	P6 XBC=0.2 XLU=1.0	P6-P1	P1 XBC=0.6 XLU=0	P1 EQ-NEQ	P6 XBC=0.2 XLU=1.0	P6 EQ-NEQ
1	Lima	67.9%	-1.6%	1.5%	3.1%	-2.0%	-0.4%	1.0%	-0.5%
2	San Miguel	88.8%	-6.8%	-1.4%	5.4%	-7.0%	-0.2%	-1.5%	-0.1%
3	Miraflores	89.6%	-8.1%	-1.9%	6.3%	-8.3%	-0.2%	-2.0%	-0.1%
4	La Victoria	77.8%	-1.8%	0.2%	2.0%	-2.2%	-0.4%	-0.2%	-0.4%
5	Chorrillos	64.6%	-4.1%	3.9%	8.0%	-4.7%	-0.6%	4.2%	0.3%
6	Santiago de Surco	90.6%	-8.8%	-2.6%	6.2%	-9.1%	-0.3%	-2.9%	-0.3%
7	Santa Anita	64.3%	-2.8%	4.1%	6.8%	-3.2%	-0.4%	3.9%	-0.1%
8	Rimac	61.2%	-2.1%	4.2%	6.4%	-2.6%	-0.4%	3.9%	-0.3%
9	San Martin de Porres	72.2%	-1.8%	0.7%	2.6%	-2.2%	-0.4%	0.3%	-0.4%
10	Callao	67.1%	-4.1%	5.2%	9.3%	-4.6%	-0.4%	5.0%	-0.2%
11	Villa El Salvador	51.1%	-2.5%	6.1%	8.6%	-2.9%	-0.5%	6.5%	0.4%
12	San Juan de Miraflores	60.9%	-6.0%	5.9%	11.8%	-6.3%	-0.4%	5.8%	-0.1%
13	Villa Maria del Triunfo	51.7%	-1.4%	3.6%	5.0%	-1.9%	-0.5%	3.9%	0.3%
14	La Molina	94.2%	-19.3%	-4.6%	14.7%	-20.5%	-1.2%	-5.4%	-0.8%
15	Ate	58.2%	-2.6%	2.8%	5.4%	-3.5%	-0.9%	3.2%	0.4%
16	San Juan de Luriganch	58.8%	-6.2%	4.5%	10.7%	-6.7%	-0.5%	5.1%	0.5%
17	Comas	63.6%	-7.3%	5.5%	12.8%	-7.6%	-0.3%	5.3%	-0.3%
18	Independencia	67.5%	-1.9%	1.4%	3.3%	-2.3%	-0.4%	1.0%	-0.4%
19	Puente Piedra	29.5%	2.5%	10.6%	8.1%	2.3%	-0.2%	12.3%	1.7%
20	Ventanilla/Callao	40.3%	-0.1%	13.5%	13.6%	-0.4%	-0.3%	15.5%	2.0%
21	Lurin	46.3%	-4.5%	19.5%	24.0%	-5.2%	-0.7%	23.5%	4.0%
22	Pachacamac	40.1%	-0.1%	33.1%	33.2%	-0.2%	-0.1%	35.4%	2.3%
23	Cieneguilla	57.5%	-15.3%	18.1%	33.4%	-16.1%	-0.8%	19.4%	1.4%
24	Chaclacayo	68.8%	-6.1%	1.8%	7.9%	-7.8%	-1.7%	2.1%	0.3%
25	Lurigancho	53.8%	-6.1%	8.9%	15.0%	-7.4%	-1.2%	11.0%	2.1%
26	Carabayllo	66.0%	-15.1%	7.4%	22.5%	-17.5%	-2.4%	8.8%	1.3%
27	Ancon	66.0%	-14.2%	11.5%	25.7%	-17.1%	-2.9%	12.2%	0.8%
28	Punta Hermosa	66.0%	-4.5%	8.0%	12.5%	-6.6%	-2.1%	9.5%	1.5%
29	Punta Nrgra	66.1%	-4.7%	1.6%	6.4%	-6.9%	-2.1%	2.0%	0.4%
30	Pucusana	66.1%	-11.8%	5.6%	17.4%	-15.0%	-3.2%	7.1%	1.4%

⭕ Successful practice of building code (P1) decreases vulnerable building ratio in all districts, more than 10% in 5 districts.

❌ On the contrary, its insufficient practice (P6) the ratio increases than that of the 2010 value.(More than 10% in 6 districts)

⭕ Earthquake accelerates this tendency due to renewal of collapsed building, resulting in getting worth in 9 districts in case of P6.
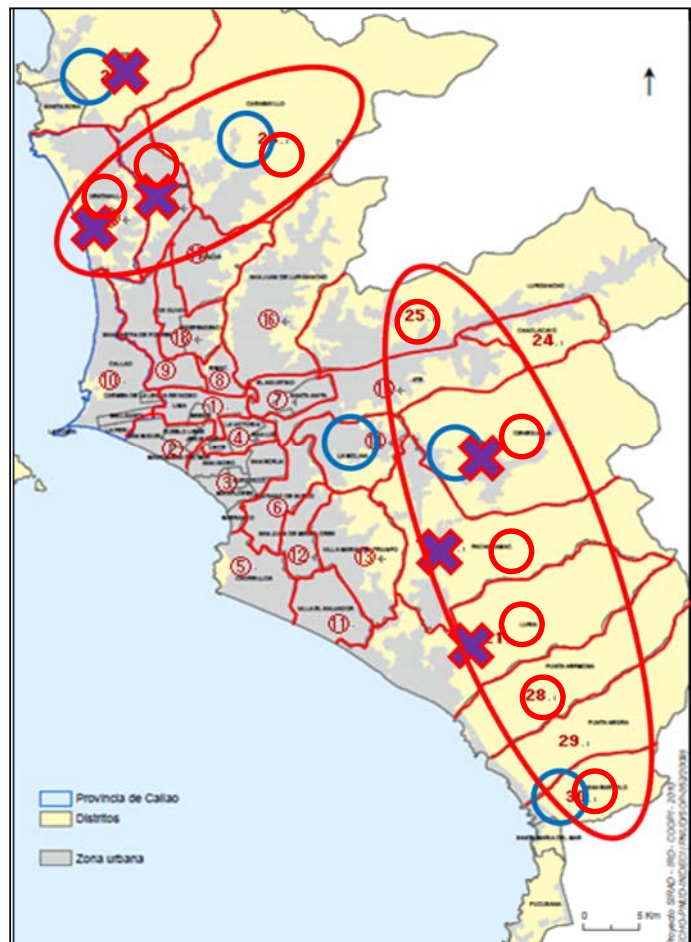
Result-3/Ratio of People Living at Vulnerable Place

	Main District	Base Year (IP)	NEQ			EQ			
			P1 XBC=0.6 XLU=0	P6 XBC=0.2 XLU=1.0	P6-P1	P1 XBC=0.6 XLU=0	P1 EQ-NEQ	P6 XBC=0.2 XLU=1.0	P6 EQ-NEQ
1	Lima	38.8%	-4.9%	-4.2%	0.8%	-1.2%	3.7%	-0.1%	4.1%
2	San Miguel	19.4%	-3.4%	-2.8%	0.6%	-2.0%	1.4%	-1.3%	1.5%
3	Miraflores	25.2%	-4.3%	-3.4%	1.0%	-2.6%	1.7%	-1.3%	2.1%
4	La Victoria	27.7%	-3.8%	-3.8%	0.1%	-1.1%	2.7%	-1.1%	2.7%
5	Chorrillos	41.5%	-7.0%	-2.0%	5.0%	-4.7%	2.3%	3.3%	5.3%
6	Santiago de Surco	45.0%	-8.0%	-4.0%	4.0%	-6.0%	2.1%	0.1%	4.1%
7	Santa Anita	44.8%	-5.8%	-3.4%	2.4%	-2.0%	3.8%	2.1%	5.5%
8	Rimac	39.4%	-5.7%	-3.0%	2.6%	-2.6%	3.1%	1.8%	4.9%
9	San Martin de Porres	31.6%	-4.5%	-3.8%	0.6%	-1.6%	2.9%	-0.8%	3.0%
10	Callao	50.3%	-5.8%	-3.6%	2.1%	-1.3%	4.5%	2.6%	6.2%
11	Villa El Salvador	18.1%	-3.1%	-2.2%	0.9%	-1.8%	1.3%	-0.2%	2.0%
12	San Juan de Miraflores	14.0%	-2.9%	-1.6%	1.2%	-2.2%	0.7%	-0.2%	1.5%
13	Villa Maria del Triunfo	26.6%	-4.4%	-2.6%	1.8%	-2.4%	2.0%	0.6%	3.1%
14	La Molina	33.8%	-10.2%	-3.4%	6.8%	-10.7%	-0.5%	-0.8%	2.5%
15	Ate	27.3%	-5.1%	-2.4%	2.7%	-3.5%	1.6%	0.9%	3.3%
16	San Juan de Luriganch	6.5%	-1.6%	-0.7%	1.0%	-1.5%	0.1%	-0.1%	0.6%
17	Comas	12.3%	-2.6%	-1.5%	1.2%	-2.1%	0.5%	-0.3%	1.2%
18	Independencia	35.4%	-4.7%	-4.1%	0.6%	-1.4%	3.3%	-0.4%	3.7%
19	Puente Piedra	10.7%	-2.7%	1.2%	3.9%	-2.5%	0.2%	3.7%	2.5%
20	Ventanilla/Callao	6.6%	-2.0%	0.3%	2.3%	-2.1%	-0.1%	1.5%	1.2%
21	Lurin	16.4%	-9.4%	6.4%	15.8%	-10.9%	-1.6%	10.2%	3.8%
22	Pachacamac	1.5%	-1.3%	1.5%	2.8%	-1.4%	-0.1%	1.7%	0.2%
23	Cieneguilla	5.4%	-4.5%	2.0%	6.5%	-4.8%	-0.3%	2.5%	0.5%
24	Chaclacayo	18.5%	-5.5%	-1.5%	4.0%	-5.4%	0.1%	0.4%	1.9%
25	Lurigancho	15.0%	-6.2%	1.1%	7.3%	-6.9%	-0.8%	3.6%	2.5%
26	Carabayllo	30.2%	-16.3%	4.1%	20.4%	-18.8%	-2.5%	8.0%	3.9%
27	Ancon	56.9%	-34.3%	22.3%	56.7%	-39.2%	-4.8%	26.4%	4.0%
28	Punta Hermosa	61.5%	-11.1%	12.1%	23.2%	-10.0%	1.1%	21.1%	9.0%
29	Punta Nrgra	18.9%	-4.6%	-1.9%	2.7%	-4.3%	0.3%	0.2%	2.2%
30	Pucusana	31.8%	-14.3%	2.4%	16.7%	-17.0%	-2.7%	6.9%	4.5%

Strict land use regulation (P1) controls living in vulnerable areas in all districts. Ancon is remarkable.

✖ No regulation policy (P6) drastically increases population living in vulnerable areas in 5 districts.

◯ Earthquake tends to increase people living in vulnerable areas in almost all districts. The tendency appears remarkably in case of no reregulation policy. More than 3% increment are seen in 13 districts.
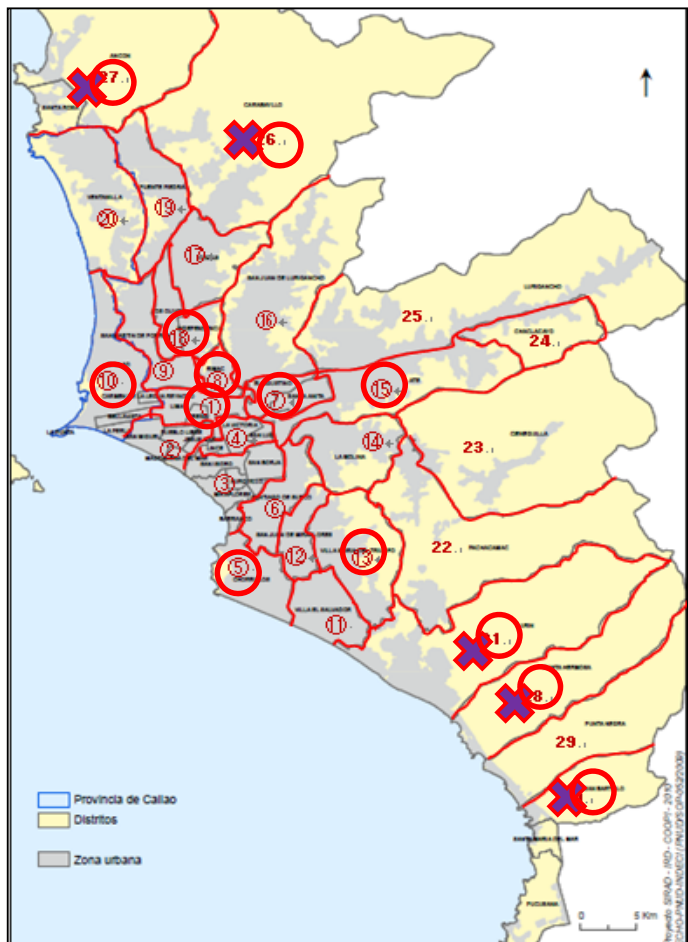
Conclusion

- Strict land use regulation (P1) restrains population growth in central parts and disperses it to the suburban areas. People tends to shift eastern and northern suburban districts after an earthquake.

- Successful practice of building code (P1) is effective to decreases vulnerable building ratio particularly in the districts where population will rapidly increase. Insufficient practice of building code (P6) accelerates increase of vulnerable building ratio after earthquake.

- Strict land use regulation (P1) is very effective for reducing population living in vulnerable areas. Earthquake tends to increase those people in all districts. The tendency appears remarkably in case of no regulation policy (P6).

- In order to make the model more accurate, some other factors such as water availability should be taken into account.