Paper:

A Simulation Model for Forecasting Urban Vulnerability to Earthquake Disasters in Lima, Peru: "LIMA-UVEQ"

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Looking ahead ten or twenty years, the urban population will inevitably increase in the Lima Metropolitan Area (LMA) of Peru. Various urban development projects will naturally be implemented in order to accommodate the additional population, and this could increase vulnerability to disasters from earthquakes if no corrective actions are taken. A computer simulation model termed LIMA-UVEQ was developed so that we could forecast the region's vulnerability to earthquake disasters over the next twenty years. Two cases were evaluated: one where some earthquake damage mitigation measures are incorporated with urban development projects and another where no such measures are implemented. With the modeling results, we then try to propose an appropriate policy mix that can be implemented in line with urban growth.

Keywords: population growth, Lima Metropolitan Area, vulnerability, land use, computer simulation

1. Introduction

1.1. Background

Similar to other developing countries, Peru is experiencing rapid population growth. Population increases in the Lima Metropolitan Area (LMA) are particularly remarkable, and this has led to the rapid expansion of built-up land in surrounding suburban areas (**Fig. 1**) [1]. The population in Peru has increased by an average of 2.0% during the last 10 years (**Fig. 2**); as the average natural increase ratio of the nation is 1.611%, the immigration ratio in LMA can be estimated to be 0.389% per year [2]. Since the population of the LMA is about 8.5 million persons as of 2010, it can be projected that the population will grow to 12.6 million persons in 2030 if the same population growth rate continues. This implies that an additional 4 million people will need to be accommodated for in the LMA.

In order for the LMA to accommodate these additional population increments, both public and private sectors will need to implement various urban development projects over the next 20 years. Development that involves deforestation and hillside grading has the potential to increase vulnerability to disasters from earthquakes if no protective measures are incorporated with the development plans [3].

1.2. Objective of the Simulation Model

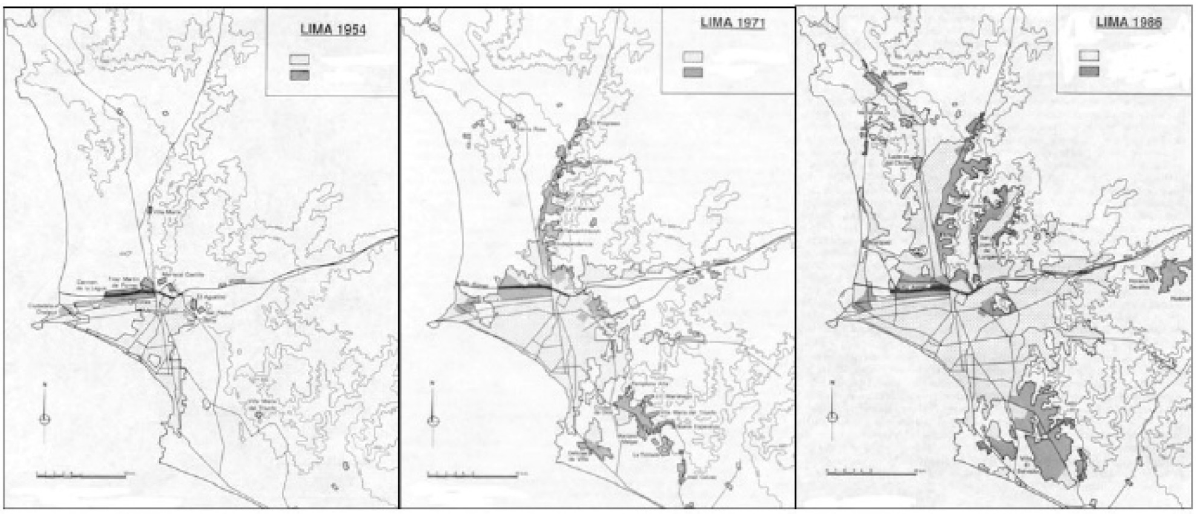
A computer simulation model – LIMA-UVEQ – was developed so that we could forecast LMA's vulnerability to earthquake disasters over the next twenty years. Two cases were evaluated: one where some earthquake damage mitigation measures are incorporated with urban development projects and another where no such measures are implemented. With the modeling results, we then try to propose an appropriate policy mix that can be implemented in line with urban growth.

1.3. Policy Alternatives to be Tested

In general, the following policies represent earthquake damage mitigation measures that should be incorporated with urban development projects: (a) building codes (which may or may not be strictly enforced); (b) protections from landslides; (c) land use regulations for private development (which may include development prohibitions in sensitive areas); (d) construction of coastal embankments. In this modeling exercise, only building codes and land use regulations were taken into account. The parameters used were as follows:

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)



Source: Driant 1991

Fig. 1. Expansion of built-up land in the Lima Metropolitan Area (LMA) for the years 1954, 1971, and 1986.

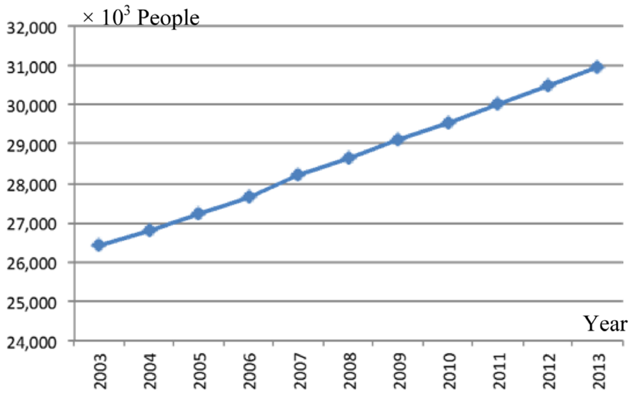


Fig. 2. Population trends in Peru (2003–2013).

X2. Land use regulation (XLU) as specified by the development prohibition ratio

$XLU = 0$: Perfect prohibition
$XLU = 0.5$: Half prohibition
$XLU = 1.0$: No prohibition policy

The policy alternatives to be tested were formulated by combining these two polices as shown in **Table 1**.

1.4. Target Indicators

For the simulations, 2010 was used as the base year and computations were executed for the following 20 years. Thus, the target year when the effectiveness of the policies could be evaluated was set at the year 2030. The best policy recommendations were based on the value of target indicators, which represent vulnerability in respective districts. The concept of vulnerability in regards to earthquakes implies potential risk of damage caused by the events, and it may or may not practically appear as damage when an earthquake occurs. Then, it can be principally measured by the number of vulnerable buildings and the population that lives in vulnerable places. Thus, policies can be evaluated by examining to what extent different practices will minimize the indices of vulnerability.

Table 1. Policy alternatives.

Practice of building code→ ↓ Land use regulation	Successful ($XBC = 0.6$)	Insufficient ($XBC = 0.2$)
Perfect prohibition ($XLU = 0$)	P1	P4
Half prohibition ($XLU = 0.5$)	P2	P5
No prohibition ($XLU = 1.0$)	P3	P6

The indices of vulnerability used in this study were formulated as follows:

A. Earthquake-resistant capacity of structures

a. Non earthquake-resistant building ratio (IB) = $BLV(i,t)/BL(i,t)$, where $BLV(i,t)$: number of vulnerable buildings $BL(i,t)$: total number of buildings

b. Vulnerability to landslides = Number of hazardous places / District area

c. Vulnerability to tsunamis = Length of coast line to be protected

B. Ratio of the population living in vulnerable areas $(IP) = IP(i,t) = PPV(i,t)/PP(i,t)$, where $PPV(i,t)$: number of people living in vulnerable areas such as steep slopes, areas that could potentially liquefy during the earthquake such as soft soil areas, and Tsunami hazardous zones $PP(i,t)$: total population of area i

In this modeling exercise, however, only two target indicators, namely A-a and B, were formulated because of the lack of data availability.

It should also be noted that the model does not take into account some vulnerability factors related to non-structural measures such as the response capacity of fire and medical services, people's awareness, and so on. Additionally, our model does not consider project costs, even though there will be costs associated with the implementation of the policies identified above. In fact, investments in urban development projects typically must decrease as disaster mitigation expenses increase, given that there is usually only one budget with limited funds to accomplish these tasks. Hence, there could be some unintended consequences such as deteriorations in the urban environment or slow economic growth. These effects were neglected in this study as well.

1.5. Comparison of the Simulation Cases

The simulations were based on two scenarios regarding a natural event. One is that an earthquake will occur during the year 2015, and the other is that no earthquakes occur during the 20 year period. The values used to assess the damage caused by an earthquake were as follows [4]:

Earthquake case: $EQ(t) = 1$ or 0 in year t
Human damage $= 1\%$,
Evacuation ratio from Lima $= 10\%$
Building damage: safe buildings $= 0.1\%$
vulnerable buildings $= 2\%$

This paper focuses on the comparison of these conditions with regards to the extreme policies in cases P1 and P6, which represent implementation of the best and worst mitigation practices, respectively. These computation cases are shown in **Table 2**.

Table 2. Simulation cases for comparison.

Earthquake	Policy (P1)	Policy (P6)
No earthquake	Case 1	Case 2
Earthquake occurs	Case 3	Case 4

Fig. 3. Aggregate of 30 zones.

2. Structure of the Model

2.1. Simulation Area and Zone Classification

The simulation area covers the whole area of Lima and the Callao Province, which consist of 43 and 6 districts, respectively. In the model, these 49 districts were integrated into 30 zones for the sake of downsizing the computer operations (**Fig. 3**).

2.2. Model Structure

Figure 4 shows a block diagram of the model. The basic structure of the model is to allocate the annual demand for residential, industrial, and commercial land over the whole metropolitan area, which will increase with the increasing population size, and to assign the respective 30 zones defined above with attractive indices for each land use. The attractive indices for residential, industrial, and commercial locations are formulated as the product of the valuables on each zone (e.g., available vacant land, accessibility to places for jobs, labor, and markets, desirable land use zoning, maturity of the respective land use, land price, and public services such as schools, hospitals, recreational areas, and so on) as follows:

Attractiveness index for housing locations

$$AH(i,t) = \frac{LV(i,t)*MH(i,t)*EASJ(i,t)*\left\{\dfrac{1}{YLPH(i,t)}\right\}}{\sum_{j\in Q(j)\neq 0}^{I} LV(j,t)*MH(j,t)*EASJ(j,t)*\left\{\dfrac{1}{YLPH(j,t)}\right\}} \quad \ldots\ldots (1)$$

Attractiveness index for commercial locations

$$AC(i,t) = \frac{LV(i,t)*MC(i,t)*EASM(i,t)}{\sum_{j\in Q(j)\neq 0}^{I} LV(j,t)*MC(j,t)*EASM(j,t)} \quad \ldots . \quad (2)$$

Attractiveness index for industry

$$AM(i,t) = \frac{MM(i,t)*EASE(i,t)*EPL(i,t)}{\sum_{j\in NMV(j,t)\geq 1}^{I} MM(j,t)*EASE(j,t)*EPL(j,t)} \quad . \quad (3)$$

Where

(i,t):	zone i in the year t
LV:	vacant land
MH, MC, MM:	maturity of the respective land use,
$EASJ$, $EASM$, $EASE$:	accessibility to job places, markets, and labor, respectively
$YLPH$:	average land price for housing/km^2 defined as $100*\{2*LH(i,0)+10*LC(i,0)+LM(i,0)\}/AR(i)$
LH, LC, LM:	housing, commercial, and industrial land
$AR(i)$:	area of zone i
EPL:	public services

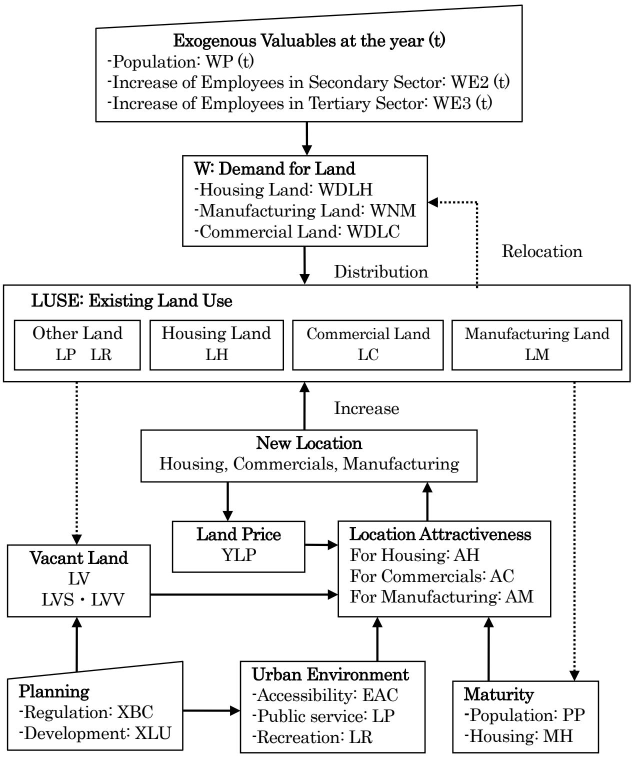


Fig. 4. Block diagram of the model.

The vacant land was divided into two types: safe land and vulnerable land. This was done so that the number of people living in vulnerable places, which is one of the target indicators, could be computed.

The residential, commercial, and industrial land allocated to each zone was converted into building area for residences, commerce, and industry, respectively.

As to the land for urban infrastructure such as roads and parks, the model computes their progressive improvement endogenously according to the following rule:

Public land (roads and other public facilities).
The same proportion of public land within the existing built-up area can be constructed in newly developed area.

Recreational land (parks, athletic fields, and so on).
The same proportion of recreational land within the existing built-up area can be constructed in the newly developed area.

3. Data Acquisition

3.1. Required Data

The following LMA and district data are required for model computations:

(On the LMA base)
As exogenous valuables:

- Predicted population by year up to the year 2030
- Predicted number of employees for two sectors by year up to the year 2030

(District based data)

a. Land use and zoning:
   - Housing land
   - Commercial land (incl. Business)
   - Manufacturing land
   - Roads and public land
   - Vacant and arable land including agricultural land
   - Rivers and other unusable land (excluded)

b. Vulnerable land:
   - Steep slopes
   - Possible liquefied areas and soft soil areas
   - Tsunami hazard zones

c. Building data [5]:
   - Number of buildings with earthquake resistance
   - Number of buildings without earthquake resistance

d. Land price for housing (defined by land use)

f. Accessibility to the city center

3.2. Land Use Data Acquisition Procedure

Among the above dataset, land use data are one of the most important elements for the simulation model. In this section, therefore, the procedure for acquiring the land use data is explained in detail.

3.2.1. General Zoning Plan of Lima

In Peru, the Institute Metropolitano de Planificacion (IMP) provides maps of the general zoning plans for Lima and the Callao Province on its website [6]. These maps are primarily drawn based on existing land use, and they can be used for geographical analyses. The authors gathered maps for 43 districts in Lima and 6 districts in the Callao Province. Each map is given as a PDF-formatted file with multi-layers that can be classified into 30 to 40 land use zones depending on the characteristics of each zone.

For example, the residential zone is classified into five types depending on height controls, the commercial zone has three categories depending on its functional centrality, and the industrial zone has six categories depending on its operation size. Since the model deals with just five categories of land use, the zones had to be aggregated. **Fig. 5** shows an example of the resulting data from the Miraflores district.

Table 3. Arranged data for simulations.

Province	District name	District			Zone			Data
		Code	Population (persons)	Area (km^2)	No	Pop	Area	
Lima (01)	Lima	101	299,493	21.98	1	381,402	25.20	○
	Brena	105	81,909	3.22				△
	Jesus Maria	113	66,171	4.57	2	320,191	23.28	△
	Puebio Libre	121	74,164	4.38				○
	Magdalena del Mar	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 de Surco	140	289,597	34.75	6	289,597	34.75	○
	El Agustino	111	180,262	12.54	7	364,876	23.23	○
	Santa Anita	137	184,614	10.69				○
	Rimac	128	176,169	11.87	8	176,169	11.87	Other region
	San Martin de Porres	135	579,561	36.91	9	579,561	36.91	○

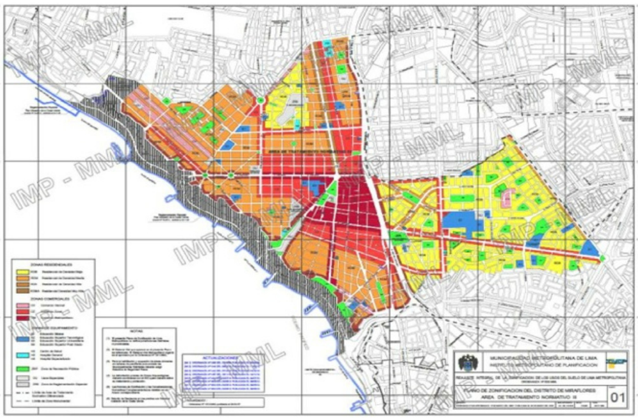


Fig. 5. General zoning plan for the miraflores district.

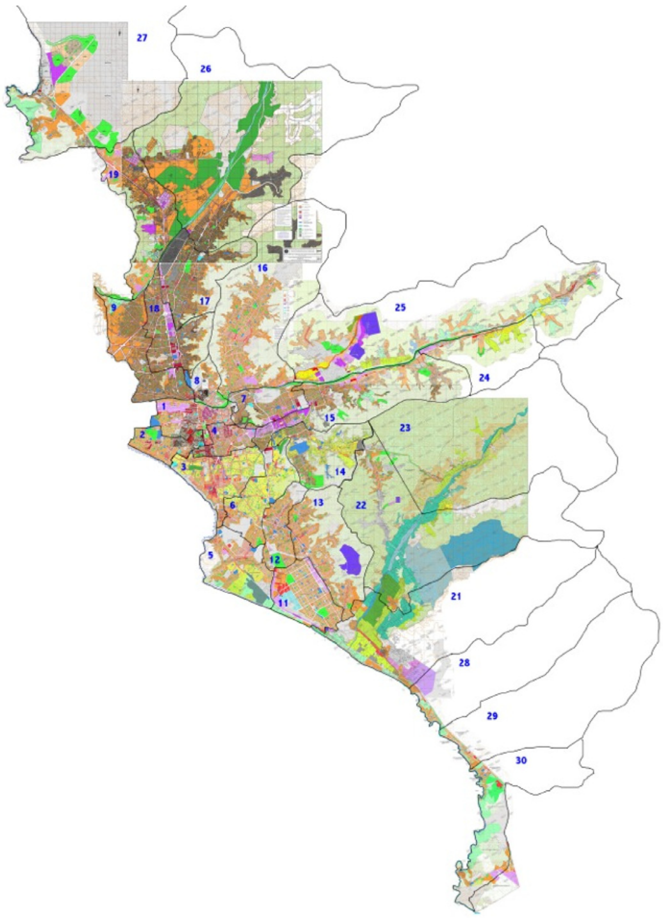


Fig. 6. Land use zoning map for the Lima Metropolitan Area (LMA). The map was made by photoshop.

3.2.2. File Conversion for Analysis

The IMP maps are given by each administrative district (49 districts). The land use data required for the model are, however, based on the 30 zones mentioned above. Therefore, the original PDF files were converted into Photoshop files so that some of the districts could be merged into 30 zones. **Fig. 6** shows the entire area of the LMA that was patched by adjusting the scale of each district map into one map. The total area and population size of the aggregated 30 zones are shown in **Table 3**.

3.2.3. Land Use Area Calculation by Photoshop

Using the new map, the areas for the original categories of 30–40 land uses were calculated by the "mea-

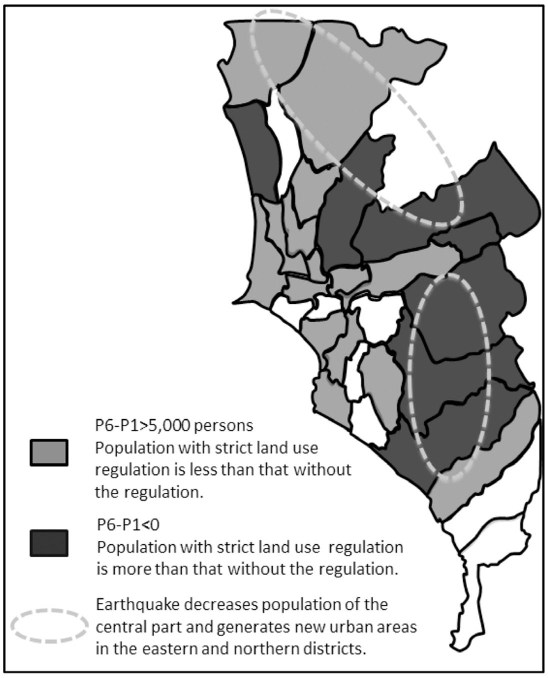


Fig. 7. Comparisons of population increases.

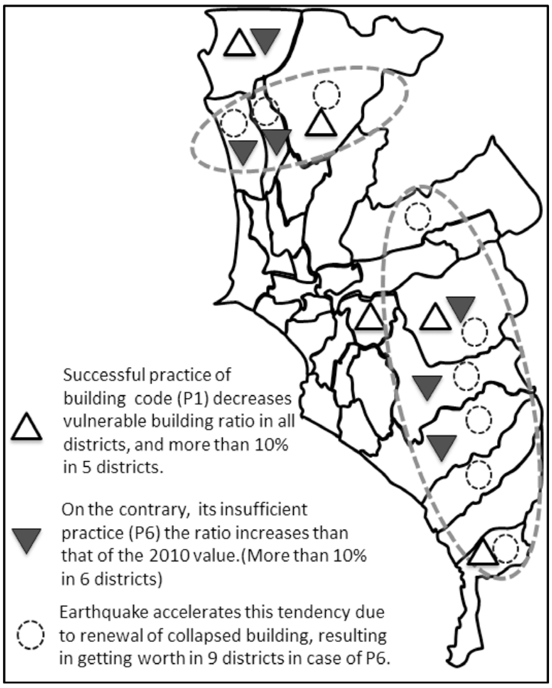


Fig. 8. Comparisonsof the vulnerable building ratio.

surement feature" function in Photoshop, which utilizes the relationship between the resolution and scale in the provided map. Then, the original categories consisting of 30–40 land uses were aggregated into the 5 land uses mentioned above for the model simulation.

4. Results

As shown in **Table 1**, the simulation was executed for six policy alternatives under the two conditions that an earthquake occurred in the year 2015 and that no earthquake occurred during the 20 year time period. Thus, 12 simulation cases were computed. In this paper, the results for the four cases shown in **Table 2** were analyzed for comparative purposes.

4.1. Population Increase by Zone

The difference in the population increase by zone in 2030 between the two policies P1 and P6 indicates the extent to which changes will occur during urban expansion. The table in Appendix A.1 shows the all of the results for the four cases presented **Table 2**. Specifically, the left-hand side of the table shows the results for the two policies of P1 and P6 in the case where no earthquakes occur during the 20 year period (NEQ).

The 14 central zones of the LMA grew by more than 5,000 persons in the case with no land use regulation policy (P6), whereas the population size increased in 9 suburban zones with a strict control policy (P1). This means that strict land use regulations restrain population growth in the central parts of the LMA and disperse it to the suburban areas. Conversely, the population tends to concentrate in the central part when no land use regulation policy is applied (see **Fig. 7**).

The right-hand side of the table shows the results of P1 and P6 in the case where an earthquake occurs in the year 2015. The results are then compared to the case with no earthquakes.

For both policies, populations in the central part of the LMA drastically decrease with an earthquake and extreme increases in six eastern (zones 21–23) and northern (zones 21–23) suburban zones were observed (see broken circles in **Fig. 7**). This implies that new urban areas in these zones will be developed after an earthquake during the reconstruction process.

4.2. Vulnerable Building Ratio

The table in Appendix A.2 illustrates how much the vulnerable building ratio changes by zone for the four cases during the 20 year period.

The left-hand side of the table shows the result for the two polices of P1 and P6 when no earthquakes occur.

Successful building code practices (P1) decrease the vulnerable building ratio in all zones, and five zones achieved a decrease of more than 10%. On the contrary, insufficient code practices (P6) will increase the ratio in most zones. In particular, the ratio increases by more than 10% in six districts (see **Fig. 8**).

The right-hand side of the table shows the results for P1 and P6 when an earthquake occurs in the year 2015, and comparisons are made for the two cases with and without an earthquake.

It can roughly be observed that an earthquake accelerates the previous observed tendencies due to the renewal of collapsed buildings, namely, that successful building code practices (P1) decrease the vulnerable building ratio more in the earthquake case than in the no earthquake

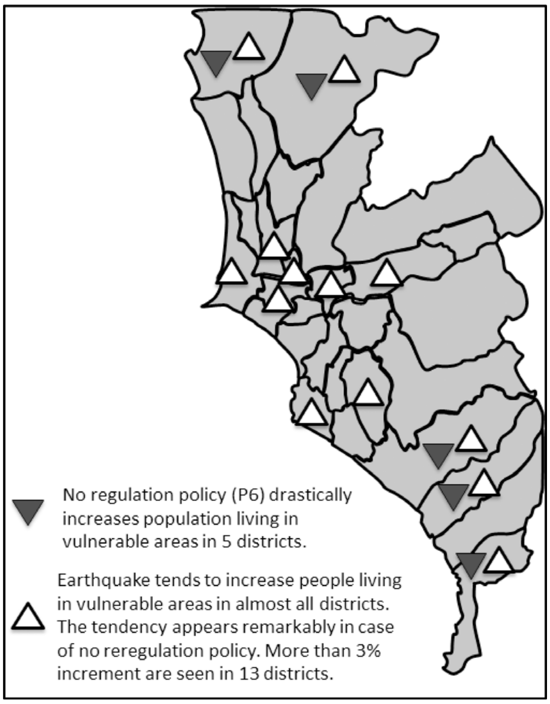


Fig. 9. Comparisons of the ratio of people living in vulnerable places.

case. Additionally, with insufficient practices (P6), the ratio worsens by more than 1% in nine suburban zones, as shown by the broken circle in **Fig. 8**.

4.3. Ratio of People Living in Vulnerable Places

The table of the Appendix A.3 shows the changes in the ratio of people living in vulnerable places for the four cases over the 20 year time period.

The left-hand side of the table shows the results for the two polices of P1 and P6 when no earthquake occurs during the 20 year period (NEQ). As can be seen in this table, all zones with strict land use regulations (P1) restrain people from living in vulnerable places. The changes in zone 27 (refer to **Fig. 3**) are particularly remarkable (names of the zones are presented in the Appendix).

However, where no regulation policy (P6) is applied, 10 zones turn positive, that is, their ratio increases. In particular, five zones (zones 21, 26, 27, 28 and 30, marked with black triangles) show drastic increases in the number of people living in vulnerable places (see **Fig. 9**).

The right-hand side of the table shows the results of P1 and P6 when an earthquake occurs in the year 2015, and comparisons are made for the two cases with and without an earthquake. An earthquake event tends to increase the number of people living in vulnerable areas in almost all districts. This tendency appears to be the most pronounced in the case with no regulation policy, and more than 3% increments were observed in 13 districts (white triangles in **Fig. 9**).

5. Conclusion

Strict land use regulations (P1) will likely restrain population growth in central parts of the LMA and disperse it to suburban areas. In other words, in order to ensure a safe living environment in the inner built-up areas, strict land use regulations will be necessary. If an earthquake occurs, people will tend to shift to six eastern and northern suburban zones. Since development activities in two zones (= districts), namely 22 (Pachacamac) and 26 (Carrabelle), appear to be particularly remarkable, proper development guidance by the local governments should be made available in these areas to avoid environmental deterioration and the generation of newly vulnerable places.

The findings from this study show that successful building code practices (P1) are an effective way to decrease the vulnerable building ratio, particularly in districts where the population will rapidly increase. It should be carefully noted that insufficient implementation of building codes (P6) will accelerate increases in the vulnerable building ratio after an earthquake, particularly in nine suburban zones. Thus, in these zones, a monitoring system for building construction should be introduced after an earthquake in order to avoid illegal construction.

Additionally, our findings show that strict land use regulations (P1) can be very effective for reducing the number of people living in vulnerable places. The most remarkable effects were seen in zones 27 (Ancon), 28 (Punta Hermosa), and 26 (Carabayllo). An earthquake

tends to increase the number of people living in vulnerable places in all districts, and the situation becomes much more severe under a no regulation policy.

In conclusion, this model provides very useful planning information for the LMA, and the process used here may be valuable for other earthquake prone regions. A more complex model can be built as more data on other social and environmental factors become available.

Acknowledgements

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References:

[1] Ana Ma Fernández-Maldonado, "Barriadas and elite in Lima, Peru: Recent trends of urban integration and disintegration," 42nd ISoCaRP Congress 2006.
[2] http://www.lima-water.de/en/lima.html [accessed March 12, 2013]
[3] Organization of American States, "Primer on Natural Hazard Management in Integrated Regional Development Planning," 1991.
[4] SIRAD Study, "Resources for Immediate Response and Early Recovery in the Occurrence of an earthquake and /or Tsunami in Lima and Callao," 2011.
[5] Y. Hirano , S. Midorikawa, and H. Miura, "Evaluation of Building Distribution Using GIS Data and Satellite Images – Part 2. Case Study for Mid- and High-rise Residential Areas in Lima, Peru –," Proceedings of AIJ, 2012.
[6] Institute Metropolitano De Planificacion, "del Plano de Zonificacion General de Lima Metropolitana," http://www.munlima.gob.pe /imp/zonificacion.html [accessed June 20, 2013]

Appendix A. Simulation Results

A.1. Population Increase by 2030

	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	

A.2. Vulnerable Building Ratios

	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%

A.3. Ratio of People Living in Vulnerable Places

	Main District	Base Year (IP)	NEQ			EQ			
			P1	P6	P6-P1	P1	P1	P6	P6
			XBC=0.6 XLU=0	XBC=0.2 XLU=1.0		XBC=0.6 XLU=0	EQ-NEQ	XBC=0.2 XLU=1.0	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%

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