ANALYSIS OF SEISMIC VULNERABILITY, APPLYING REMOTE SENSING AND GIS

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Abstract
After the ending of the decade for the reduction of the natural disasters, declared by United Nations in 1990, a notable impulse has been given to the application of new technologies for land use management in order to reduce the impact that natural catastrophes imply. The considerable economic and human life losses that result from disasters require new effort to improve current tools for detecting and managing risk. This work suggests a methodological framework to map seismic vulnerability in urban environments. The method begins from the spatial analysis of geographical information obtained from different sources, remote sensing, national and local census and field data collection.

The main objective is to identify seismic vulnerability of the population of a city. For this, we developed a model of seismic vulnerability that is based on the variables of localization of critical installations and fragility of the construction. So, dynamic cartography was obtained, based on the variation time-space, derived of the levels of occupation of population of the different sectors of the city. This work was developed for the authors in the city of Africa, located in the North of Chile, zone that possesses a great seismic frequency.

Introduction
From the point of view of administration of seismic risk. Chile's experience is similar to most of the countries that share this natural danger. The risk can be considered from two perspectives: first, government with the primary response emphasizing post-event measures; this has yielded little in terms of prevention of risks. Some mitigation measures such as the preparation of the population or the consideration of the natural risks in planning the interior of the cities have not been sufficiently considered. A second and more scientific perspective emphasizes the understanding of a geophysical vision of the processes that originate in the pre-event. This results in the phenomenon being understood exclusively from a physical focus emphasizing the knowledge of the origin and development of the seismic waves. Yet this ignores the understanding of the impact of the earthquakes on inhabited zones. Open problems like the prediction of the moment of the seismic occurrence have been considered as of great complexity and of an almost extreme inefficiency.

In face of this situation, this work,describes a model that develops understanding of the event, in different stages, by means of the generation of cartography of seismic vulnerability.

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Considering the urban characteristics of the city of Africa, we proposed to generate cartography of seismic vulnerability, basing us in two aspects that are subject to be analyzed from a space perspective: the critical installations, understood like those urban infrastructures that adopt a critical character during the occurrence of a earthquake, because they commit directly to the masses of population to the interior of the city, and the fragility of the construction, defined in terms of quality of seismic answer of the constructions. The critical installations were conceived like variables that exercise an arithmetic action on the seismic vulnerability, according to the character that they adopt during the occurrence of a earthquake, in accordance with the exhibition of the population to the risk.

On this base, a compound cartography was developed that considered the population's fundamental vulnerability. We consider the very dynamic character of population spatial location due to its mobility in the interior of a city at various times. In our outline, the variables (critical installations and fragility of the construction) acquire a great importance in the calculation of the seismic vulnerability of the city, that vary during different days of the week and hours of the day.

Theory and Methodology

The information used in this work was derived of data of the census of the city, attendance statistics of school students, the number of individuals assisted in the health services, and other occupation were considered.

Also, information on land was obtained taking of ground control points (GCPs) with GPS and from helicopter, of all those installations that were considered as of great potential of fragility during the occurrence of a earthquake.
The critical installations, identified starting from approaches expounded by OEA for the realization of this type of studies (OEA, 1977). According to these approaches, and considering the own characteristics that possess the city of Africa, the following elements in the cartography of critical installations were incorporated:

1.-Infrastructure of public security and defense (barracks of firemen, hospital and other infrastructures of health and Police).
2.-Centers of occupation of high density (institutions of education, cinemas, stadiums and sport installations, university, hotels).
3.-Infrastructure of transport (terminal of buses, stations of railroad).
4.-Urban infrastructure (deposits of drinkable water, deposits of fuel, gas stations, centers of storing of minerals and chemical).
5.-Industrial infrastructure (industries with deposits of corrosive, inflammable and toxic materials).

Once identified these installations by means of work of field, using a GPS, was proceeded to incorporate this information in a spatial database compounded for the city.

With the objective of generating useful information in order to identify the fragility of the construction, as well as related variables with urban infrastructure, an image IRS 1C (P) was acquired , that possess a space resolution that responds to the requirements of this work.

Analysis of the critical installations of the city of Africa

The critical installations of the city manifest a clear concentration in very specific sectors. In the town are concentrated hotels, institutions of higher education, and some schools of secondary and basic education. The centers of health are located around the Hospital Juan Noé and San José. The industries with dangerous material, as well as the zones of storing of minerals and chemical, are located in the industrial district.

A conventional map of critical installations that only shows their location does not properly show the true spatial differentiation of risk. Although they share some critical characteristics during the occurrence of a quake, outcomes are not the same due to seismic vulnerability variability in the city, because their characteristics present sunstantial differences from a spatial and temporary point of view. For this reason, we classify them in the following three groups on the base of the spatial impact and temporary behavior that they manifest during the development of an earthquake (Zavala and Chuvieco, 2001):

-· Receiver critical installations: those constructions that imply a mass of population.
-· Powerer critical installations: those installations that bring about an increase of the risk, powering the effects of the earthquake.
-· Mitigator critical installations: infrastructures that palliate the damages of the event.

Receiver critical installations
Occupation statistics mentioned previously are tabulated in the following table; they identify the population with possibility of being affected at receiver critical installations:

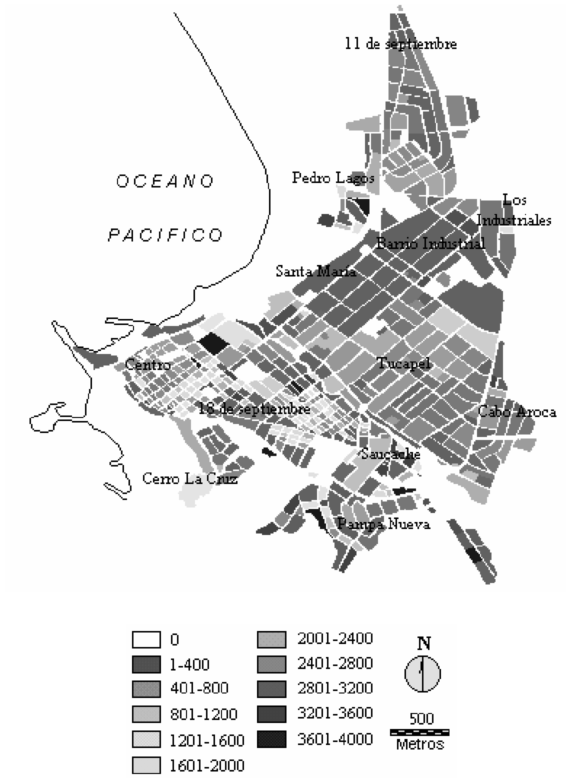
Table 1 Population occupant of the Receiver critical installations

Instalations	Monday to Friday 08:00-14:30 h.	Monday to Friday 14:30-21:00 h.	Monday to Friday 21:00-08:00 h.	Weekend 08:00-22:00 hrs	Weekend 22:00-08:00 hrs
Schools	13626	494	0	0	0
High Schools	9940	9707	0	0	0
Cinemas	0	320	475	727	0
Terminal station of buses	990	550	700	700	700
Hotels	0		299	299	299
University	2059	2600	0	0	0
Estadiums	0	0	0	5850	0
Terminal stations of railroad	150	150	0	120	0
TOTAL	26765	13821	1474	7696	999

By examining this table it is clear the most important amount of population comes during the mornings of the week (Monday to Friday of 08:00 to 14: 30 h.), with a total volume of 26,765 inhabitants, diminishing considerably during the afternoons of the same days (14:30 to 21:00 h.). This is due to the decrease of students of the level of basic and university education during the afternoons. In this way, infrastructures that are critical during the mornings, like the basic schools, lose this character during the rest of the days and periods of the week, due to the absence of students in their classrooms.

As with the space change patterns of human occupation we found it useful to consider the spatial mobility of the inhabitants of the city, starting from the identification and analysis of the infrastructures that amass population along the day and of the days of the week. We then calculate the density of effected population during the different periods of the day and of the week starting with those attempting to enter the receiver critical installations; this kind of analysis was also completed for city labor statistics from city occupation maps, using GIS processing. An example of the cartography obtained is shown in the following map that corresponds to the morning period of labor days.

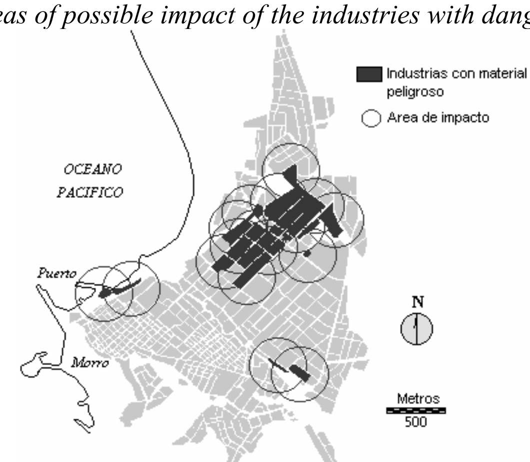
Figure 1 Localization of the population. Monday to Friday of 08: 00 to 14: 30 h..



Powerer critical installations: analysis of ratios of impact

Powerer critical installations were identified on the base of the types of danger that they present. These installations have permanent vulnerability since these entirety work 24 hours per day. We generated a map for each type of installation, according to a space approach of impact, proposed by Firemen from Chile. The following map shows the areas of possible impact of the industries with dangerous materials.

Figure 2 Areas of possible impact of the industries with dangerous material.



Once these new cartographies were produced, we used them to calculate the population committed in the face of an eventual collapse of the powerer critical installations, crossing the information derived of the maps of daily localization of population with the map of powerer critical installations, by means of GIS, obtaining the following table:

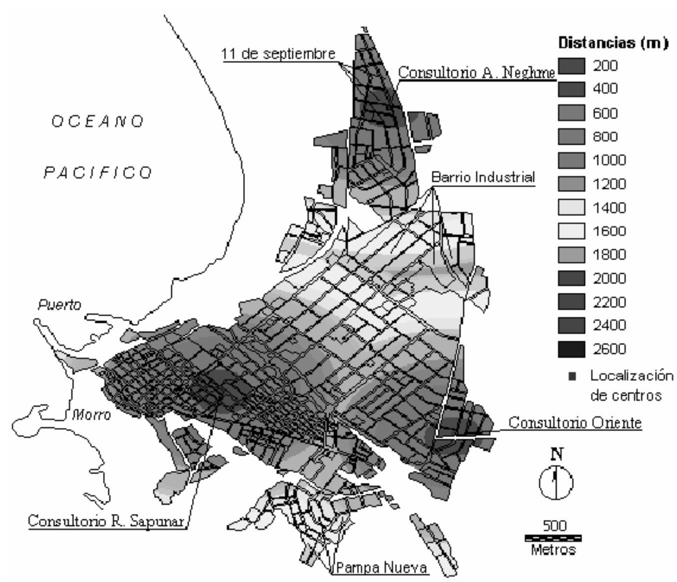
Table 2 Population committed by powerer critical installations in different periods of the week.

	Monday to Friday 08:00-14:30	Monday to Friday 14:30-22:00	Monday to Friday 22:00-08:00	Weekend 08:00-22:00	Weekend 22:00-08:00	Average
Mining storing/ chemical	4544	4953	2337	2423	2423	3336
Deposit of fuel	3459	3096	2811	2867	2811	3008
Industries with Dangerous material	8032	8183	3018	3152	3018	5080
Gas stations	12578	14756	13445	14572	13445	13759
Big gas stations	28208	28220	5016	5016	5016	14295
Deposit of water	4342	3546	1278	1278	1278	2344
TOTAL	61163	62754	27905	29308	27991	41.824

Mitigator critical installations

Infrastructures like hospitals and other centers of health were examined in terms of calculations of distance between these and the different sectors of the city, because in the occurrence of a seismic phenomenon, and the population that should move to these installations. The police and fire forces that should move to the affected zones were analyzed by means of calculations of distance with powerer installations. This can be seen in the following map, that shows the calculations of distance of the centers of primary attention, by means of a GIS.

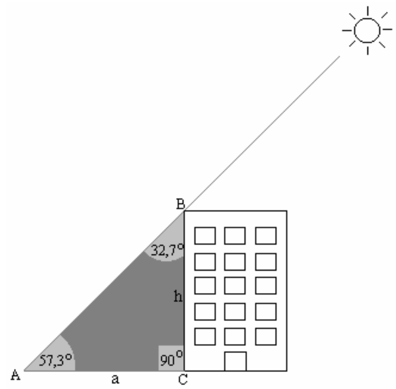
Figure 3 Distances of Centers of Primary Attention



Generation of map of height of buildings and installations

Following authors like Cheng and Thiel, (1995), we thought that the heights of the constructions could be calculated by means of satellite images, starting from the knowledge of the length of shadow, the angle of solar elevation of the image, and ground slope. For this reason, we proceeded to calculate the heights of the constructions like could see in the figure number 4. For this, we used an *IRS* 1C image, corrected of 5.8 to 5 meters, by means of cubic convolution.

Figure 4 Calculate of the height of the constructions.



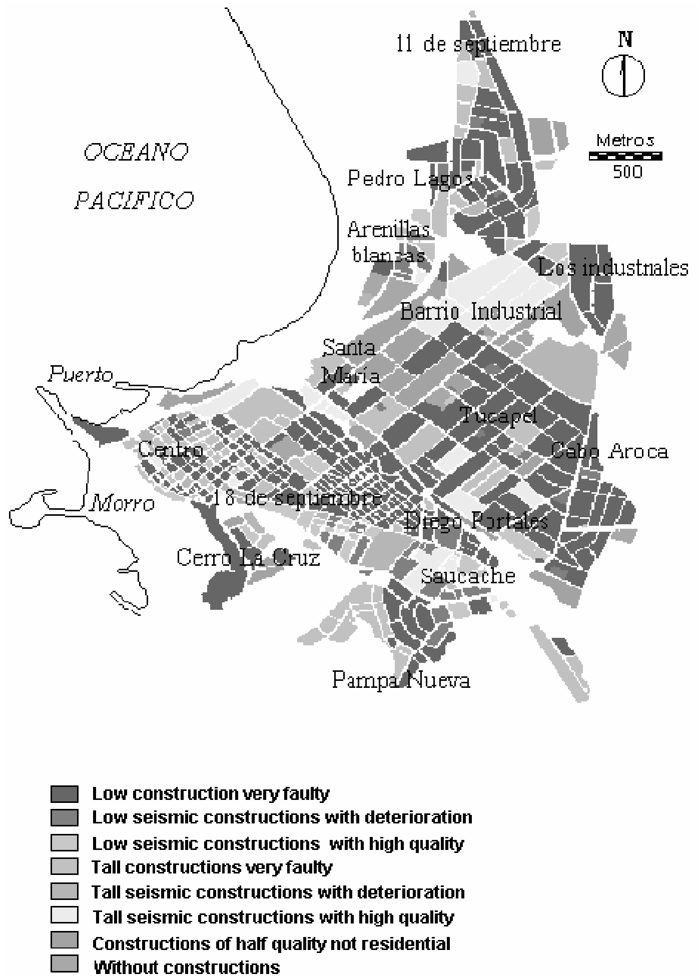
Where: The angle of sun elevation that possesses the image is of 57.3º (57º18').
The longitude of the shadow was calculated starting from the number and size of the pixel (5 meters), in the central column of the shadow of the constructions, because this has fewer interference than other columns. So, for a shadow of 5 pixels, the height of the building that the projects was calculated in 13.51 meters.

The results were verified in 20 buildings, selected by means of random sampling, with digital altimeters of high precision, reaching an error average of 1.5 meters.

<u>Generation of map of quality of the construction</u>
To improve discrimination and better precision, we opted for adding layers of additional information to the original band, based on the texture, that corresponds to the spatial variation of the gray tones that present an image. So, following Berger (1996), and Molina and Chuvieco (1996), and considering the objective of differentiating the quality of the construction, we proceeded to generate bands of homogeneity and dissimilarity for specil analysis.

Based on this accumulated knowledge of the area of study, we proceeded to apply a supervised classification based on training classes. For the assignment of the pixels of the image to one of the categories previous defined, was used the method of Maximum Likelihood; after obtaining the classification to level of pixel, a modal approach was applied in order to assign to the different sectors of the city, the dominant class, generating the map of the figure number 5.

Figure 5 Spatial distribution of the quality of the construction.



The quality of construction map (figure 5) was verified by land truthing. For this, we selected the 5% of the total of the existent polygons in the map base, by means of stratum random sampling. The obtained result reached an error of assignment average of 14.7%.

Results

Integration of the information

The several cartographic maps (layers) generated were cross referenced and analysed by means of the application of a GIS, superimposing the cartography obtained by means of arithmetics approaches. So, the map of population was added to the quality of construction. Their result was multiplied for the map of synthesis of the powerer installations, obtaining a second map of synthesis, to which subtracts to the map of synthesis of the mitigator installations. This is the key resulting generated map; it contains 10 classes of increasing seismic vulnerability based on all considered variables. It indicates a proportional increase of the vulnerability in the city from minor to major vulnerability. This model of integration can provide dynamic cartography; for example see two maps corresponding to the periods of the mornings of labor days and mornings of the weekends.

Figure 6 Map of Seismic Vulnerability of the city of Africa. Monday to Friday, 08:00 to 14:30

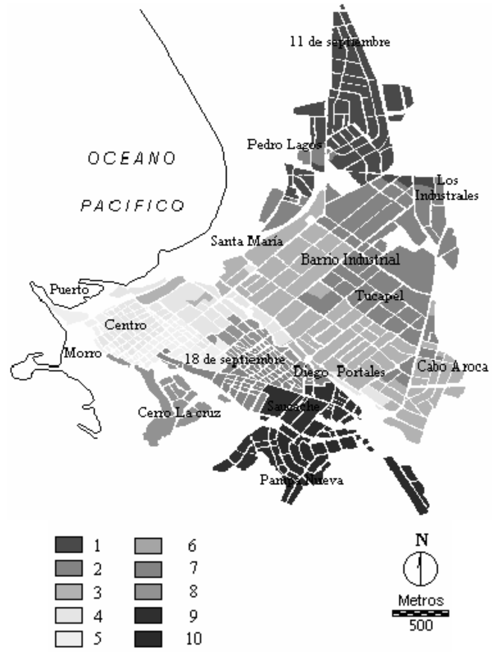
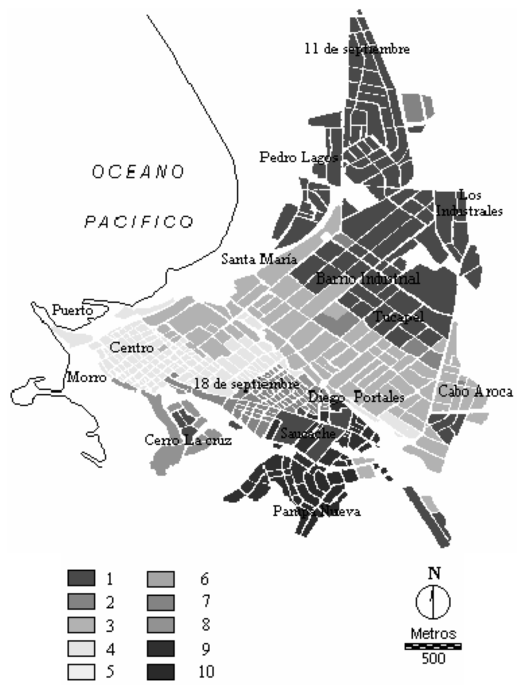


Figure 7 Map of Seismic Vulnerability of the city of Africa. Weekend, 08:00 to 14:30 h.



Discussion

Based on the generated antecedents, the seismic vulnerability is spatially differentiated in the city of Africa, like consequence of the behavior in time and space of the installations that we have denominated like receiver, powerer, and mitigator.

The contribution that could give us information obtained by remote sensing is profiled of great importance, as well of information of quality of the construction, that will add a new dimension of analysis that will allow to improve the reached achievements, but rather also in the bringing up to date of antecedents obtained of different sources and therefore of temporary different origin.

We thought that in the face of the impossibility of prediction of the moment of an earthquake, efforts should be turned to establishing how an earthquake effects an inhabited center. In this context the present work is located, that seeks to contribute an outline methodology in order to carry out maps of seismic vulnerability in urban environments, starting from the spatial analysis of the territorial information that one could obtain by means of remote sensing and other statistical and cartographic sources. In this context, the GIS contribute a coherent structure for the integration of this type of variables, and also facilitate the execution of the model and the cartographic representation.

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References

Berger, M. (1996) Separability analysis of landuse classes using MOMS-02 data in combination whit extracted texture images. In Proceeding of the MOMS-02 Simposium. EARSel, pp. 137-142. París.

Cheng. F.; Thiel K. (1995) Delimiting the building heights in a city from the shadow in a panchromatic Spot Image. In International Journal of Remote Sensing. 16 (3): 409-417.

Molina, Z. ; Chuvieco E. (1996) Evaluacion de indices texturales para discriminar morfologia urbana:analisis de la ciudad de maracay. In Revista de Teledetección 1996; 7:49-57, España.

O.E.A. (1977). Multiple hazard mitigation. National Academy Press. Washington. U.S.A. 255 p.

Zavala, P. ; Chuvieco, E. (2001) Análisis de la vulnerabilidad sísmica mediante teledetección y S.I.G. In Proceeding del IX Simposio SELPER. Iguazú, Argentina.

Zavala, P. (2002) Análisis de la vulnerabilidad sísmica aplicando teledetección y SIG: el caso de la ciudad de Arica. Tesis Doctoral. Departamento de Geografía, Universidad de Alcalá, España.