

A PROPOSAL OF TSUNAMI RISK ASSESSMENT METHOD FOR IQUIQUE CITY, CHILE

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ABSTRACT

A method for tsunami disaster risk assessment for Iquique, northern Chile is tested and proposed in this dissertation. It is based firstly on archive research and a collation of available data, followed by the partial application of the Project Cycle Management (PCM) method for systemic description of the city, and to identify issues that block the development of risk management. From this, and in consideration of previous research, it is inferred that the political benefit of risk management in Chile is not always clearly perceived, and, as responsible stake-holders are mainly government institutions, this causes an impasse in the system. Consequently, this study suggests ways to clarify the concept of risk, making it easier to manage. This entailed developing a method of assessing tsunami risk, using a matrix of hazard v/s impact for risk calculation suitable for Chile, i.e. taking account of local conditions in order to generate appropriately risk scales.

The city's vulnerabilities were considered as a pyramid of four-levels, mathematically connected through the weighted sum of impacts, and subject to hazard exposure. The reliability of hazard estimation was considered at the second level, so introducing an incentive to improve the quality of hazard input. The probability of hazard occurrence was assumed in two possible scenarios, due to the lack of statistical data on seismic behavior for northern Chile. The physical input for hazard scenarios was taken from current official inundation maps, and from the estimation of vulnerable zones through analysis of remote sensing data.

The outcome of this research includes maps of risk distribution and radar charts indicating different types of vulnerability, clearly showing variables which need to be considered for effective risk reduction.

Regardless of assumptions due to lack of data and the limited scope of this work, the risk level in Iquique is high, reaching intolerable levels in some cases. For higher probability of hazard occurrence, the effect of a combined earthquake and tsunami would certainly generate a crisis situation.

Keywords: Tsunami, Risk Assessment, Risk Evaluation, Vulnerability.

1. INTRODUCTION

The earthquake and tsunami that occurred on February 27th 2010 in central Chile caused a profound change in terms of how tsunami disasters in Chile are perceived, and revealed multiple vulnerabilities in crucial aspects of their management. Soon after that event the Japanese International Cooperation Agency (JICA) and the Japan Science and Technology Agency (JST), proposed to the Chilean government the development of a joint research project on tsunami disasters, called "To Develop Technologies to Improve Communities and People in Chile, Japan and other countries to be Well-prepared and Resilient against Tsunami" (JICA-JST Project). The research presented in this paper is part of Working Group 4 of that project, which its overall objective is an "Investigation of a planning method for local government system[s] to be functional after the disasters/Business Continuity Plan". This study is a preliminary proposal for tsunami disaster risk management in Iquique (20°13.0'S, 70°8.5'W), based on the compilation of various procedures. Several criteria have been outlined in regards to the scarcity of information available for risk evaluation.

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The challenge undertaken in this study is to help to connect the scientific or specialized world of tsunami disaster risk research, with decision-makers, managers and stakeholders involved in tsunami disaster risk management.

2. DATA

The thesis has been structured starting with a deep bibliographic research to generate the basic background and data collation for risk evaluation. The background has been described in terms of the contextualization of risk concept; earthquake and tsunami threats in Chile and particularly in the northern part of the country; and tsunami disaster management in Chile.

From background study can be stated that the concept of risk in Chile has not been fully applied in tsunami studies. Also, the background study allows justifying the consideration of extreme scenarios of tsunami hazard, regarding to the seismic behavior of the subduction zone in northern Chile. And finally, the country has shown fragility aspects in disaster management, mainly due to weakness in some institutional aspects and a wide lack of planning, among other reasons (PNUD, 2012).

3. THEORY AND METHODOLOGY

The methodology has been composed by two main parts, considering the city of Iquique as target: the description of the system in terms of hazard and vulnerabilities; and the risk assessment, which is actually the core of the study. Once described the system a hypothesis is inferred, and it is supposed to be proven through the risk assessment. Thus, the hypothesis is the link that connects both methodological aspects. Finally, results calculation is focused in total risk for the whole city described in detailed maps and diagrams, among other complementary information showing the method capacity to go deeper into specific risks analysis.

3.1 Overview of risk assessment in terms of hazards

Iquique is positioned in a zone where the occurrence of a major tsunamigenic earthquake, with a rupture located between parallels 19°S and 23°S, can be expected. With this in mind, and considering the usual behavior of subduction earthquakes in Chile, the hazard has been defined as at least one tsunamigenic earthquake with magnitude higher than $M_w=8.5$, among other characteristics.

For the purposes of risk evaluation in this thesis, hazard estimation is derived from the official tsunami inundation map (scenarios A and B), using the seismic parameters of the 1877 earthquake (SHOA, 2012). While inundation depth at Iquique is known, other physical parameters can only be estimated, so a worst case scenario has been considered.

Another hazard estimation has been applied, using the data of vulnerable zones obtained from Remote Sensing and spatial multi-criteria analysis tools (scenario A-RS). This procedure was originally calibrated for Kesenuma, Japan, and has been applied as a test (Sambah and Miura, 2012).

In terms of probability of occurrence, the scenarios considered are the following:

- SCENARIO A: The event will occur within the next 10 years (Probability factor = 5)
- SCENARIO B: The event will occur within more than 500 and less than 1000 years (Probability factor =2)
- SCENARIO A-RS: The event will occur within the next 10 years (Probability factor =5)

3.2 Overview of risk assessment in terms of vulnerabilities

A basic Project Cycle Management (PCM) procedure has been applied in order to identify the main stakeholders, vulnerabilities, vicious circles and virtuous circles, with the goal of establishing a

systemic understanding of the city. This procedure involves a stakeholder analysis, problem analysis and objectives analysis. Once the objectives analysis has been performed, a detailed study of issues extrapolated from identified problems is proposed, with the aim of deriving measurable parameters for associated vulnerabilities.

The stakeholders analysis has been performed through a SWOT method application, which allows deducing needs of urgent software countermeasures for tsunami risk mitigation. Also, from the stakeholders analysis the Local Government has been selected as implementing agency.

Based on the Earthquake Damage Estimation in Yamaguchi Prefecture (Yamaguchi Prefecture Earthquake Disaster Prevention Committee, 2008) and the Communal Response Plan (Municipalidad de Iquique, 2011), the problems due to tsunami disaster in Iquique have been proposed. It has been done following three aspects: Human Casualties; Economic Losses; and Social problems. Those problems have been systematized and detailed in order to infer vulnerabilities, and a series of objectives has been raised as 'reduction of specific damage', considering that 'damage' is associated to hazard impact over some vulnerability of the system.

The core objective is the Tsunami Disaster Risk reduction, which can be achieved by the reduction of damage in a cause-effect chain that configures the objectives tree. For purposes of this thesis some of those objectives have been selected to test the method and detect the relation between hazard and specific vulnerabilities that configures each problem.

From the systematization and analysis performed, can be inferred that the vicious circle that blocks the disasters risk management in Chile relies in the absence of conditions to turn it politically profitable in short or medium term, probably strongly based on the lack of preparation and awareness in the Governmental institutions, either at National or Local levels. If it is supposed that any component of the system can modify its behavior depending on the existing incentives, so the solution proposed in this thesis is mainly focused in clarifying the concept of tsunami disaster risk with the development of tools for its easy understanding by the decision-makers and stake-holders, and to establish an arbitrary standard for risk measurement, to show its current levels and thus to propose future targets for risk level. The expected consequence of this proposal is the feasibility to introduce political pressure for improvement of Tsunami Disaster Risk management.

3.3 Risk Assessment

The Figure 2 shows the general flowchart of this risk assessment. The risk calculation procedure used in this work has been based on Eq. (1), and considering the weighted summation of lower level risk, according to Figure 1, with assumptions for weight factors through a scale of importance.

$$R = P \times I \quad (1)$$

With:

R: Risk

P: Probability of occurrence of Hazard scenario

I: Impact or level of consequences, depending on vulnerability and exposure.

In the implementation stage, the weight factors, and in general the whole systematization of the city, should be confirmed through interdisciplinary work, towards the application of Analytical Hierarchy Processes.

Due to the scarce availability of information for risk evaluation in Iquique, the value of impact is open to be evaluated in a qualitative way, form inference of damage or consequences of hypothetical hazard scenarios. Also several criteria has been defined for exposure, when needed.

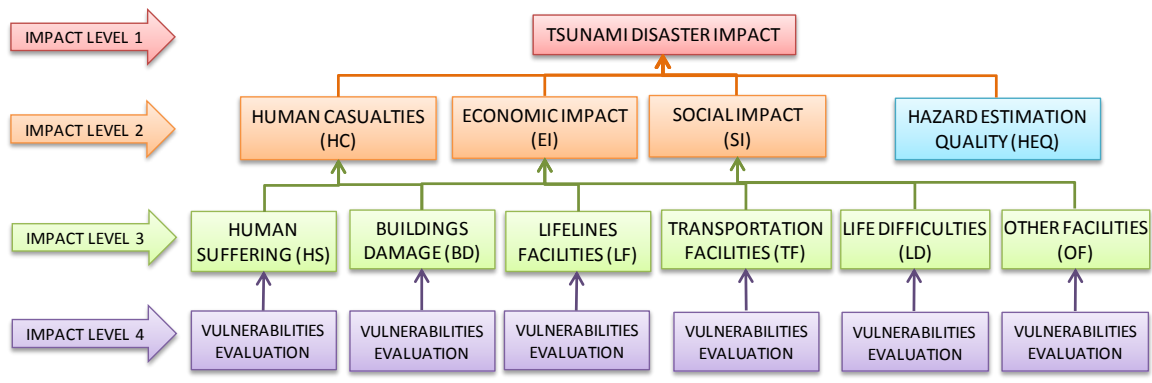


Figure 1. Flowchart for impact calculation.

Two methods for graphical presentation of results have been utilized. First, layered GIS maps for risk distribution and second, a series of radar charts as shown in Figure 3.

4. RESULTS AND DISCUSSION

The maximum tsunami disaster risk levels calculated for Iquique reached to 21.3, 8.3 and 21.3 for scenarios A, B and A-RS respectively, in a scale from 1 to 25. The results obtained correspond to ‘HIGH - INTOLERABLE (CRITICAL)’ condition for scenarios A and A-RS, and ‘MEDIUM - TOLERABLE (UNDER CONDITIONS)’ for scenario B. Using the software ArcGIS 10.0 for raster calculation, the risk has been graphed in a series of maps, introducing exposure criteria. There can be observed that the risk associated to tsunami disaster is distributed across the city, with strong influence of inundation area and population density.

Regardless to the assumptions made, the results obtained for risk level in Iquique are showing the highly vulnerable condition of the city against the defined threat. The classification of risk as ‘critical’ is suitable due to the last experiences in Chile, with special focus in social impact. Thus, the results obtained are locating the main responsibility in political headquarters, which is consistent with the definition of Local Government as implementing agency, and also with the definition of beneficiaries. The relative importance of vulnerability components and weight calculation are not so relevant in results obtained, due to the diversity of factors involved. However, a further optimization based on agreement of stake holders and with a robust scientific background is recommendable.

The systematization of Iquique allows clarifying its vulnerabilities, such as the situation of administrative buildings of Local and National Government; the high levels of vulnerability in the Port and ZOFRI commercial zone; and the high vulnerability of fire fighter stations.

The proposed methodology and results presentation allows knowing the composition of each vulnerability and its contextualization in the general risk condition of the city. Also, the analysis performed allows realizing the importance of software measures to reduce vulnerability, in a context without hardware countermeasures against tsunami impact.

The quantification of risk is very sensitive to the hazard input, and the current knowledge about seismic behaviour in northern Chile is heterogeneous in terms of quality. The Hazard Estimation Quality impact introduction at the second level of vulnerabilities can be an incentive for its improvement, allowing to start risk measurement without waiting for ‘the best inundation model’.

The availability of information is a key factor to reduce the risk levels of the city and its components. It is strongly needed to develop standards and procedures for damage assessment of buildings after earthquakes and/or tsunami impact in Chile.

The results obtained show a wide homogeneity of risk over the city, probably influenced by the assumption of relative high impact of earthquake respect to tsunami, affecting lifelines facilities. It is strongly recommended to get deeper understanding of indirect consequences, its time-dependent condition and the way they can be controlled.

Finally, it is fundamental to strengthen the Local Government capacity to cope with disaster scenarios, including them in city planning and community fostering. That can be achieved through the generation of reliable databases to complement, strengthen and feed this risk assessment method.

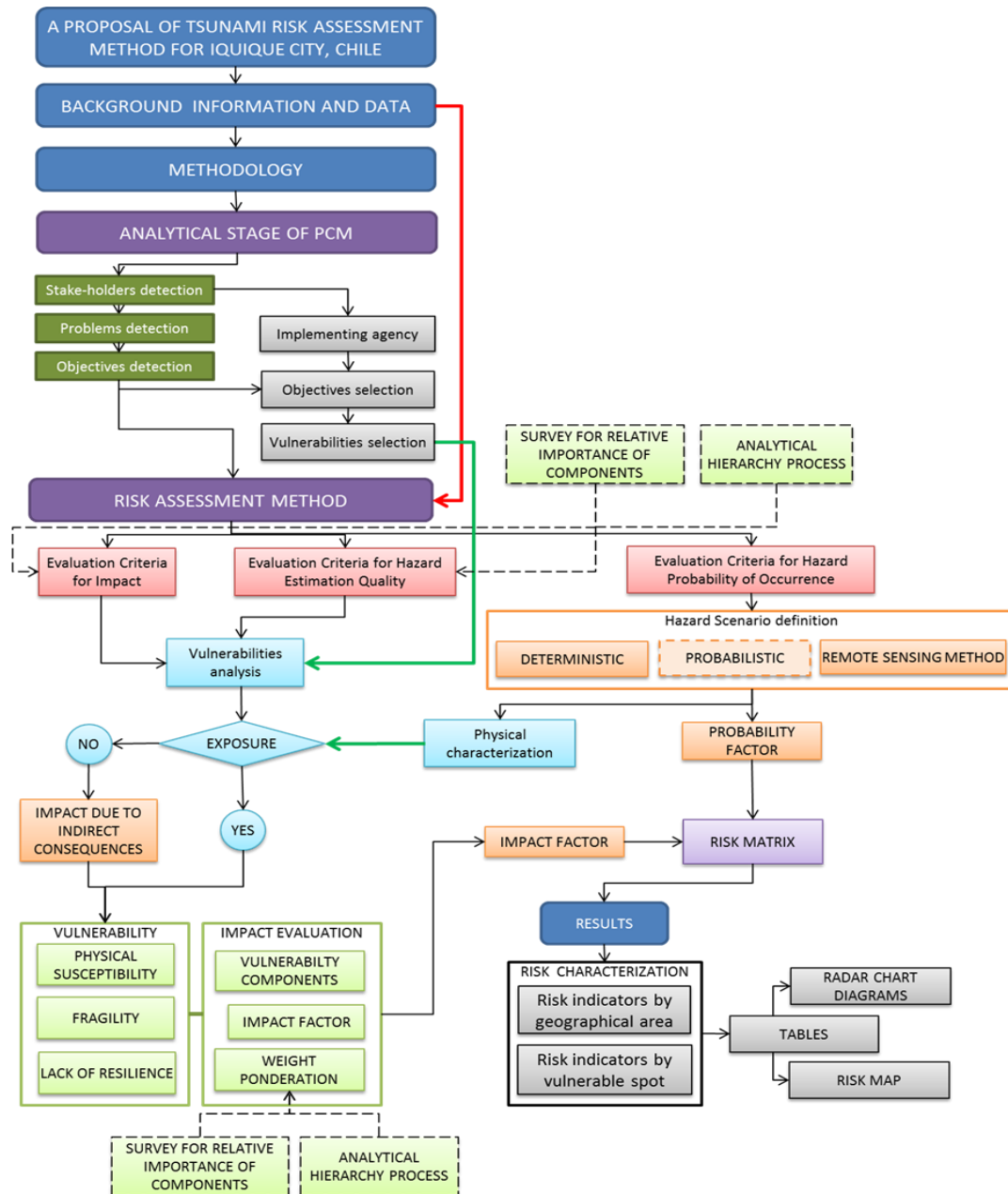


Figure 2. Flowchart for risk assessment method. The segmented lines represent tasks that must be done during implementation plan.

5. CONCLUSIONS

A method for Tsunami Disaster Risk Assessment in Iquique has been proposed, with the aim to generate an instrument for local management, from Local Government down to all stake holders, if possible. The analysis performed, using several assumptions for input data and criteria for its description, shows intolerable levels of risk if the earthquake and tsunami occurs in short to medium term. In consequence, it is urgent to generate conditions for the application of this method, and

introduce the certainty of risk disaster based on the evidence of both hazard potential and vulnerabilities in the system.

The implementation of this kind of method for Tsunami Disaster Risk Assessment in Iquique can trigger a virtuous circle of risk management, so its improvement and optimization should be a priority in following stages of JICA-JST Project. In fact, the proposed methodology and results obtained are consistent with the objectives of the Working Group 4: Investigation of a planning method for local government system to be functional after the disasters, and gives a clear disaster scenario description for Business Continuity Planning.

The analysis performed at Iquique reveals a high risk of crisis situation in case of strong earthquake and tsunami occurrence. Thus, is highly recommended to improve this risk assessment method and applied it as soon as possible for control of vulnerabilities.

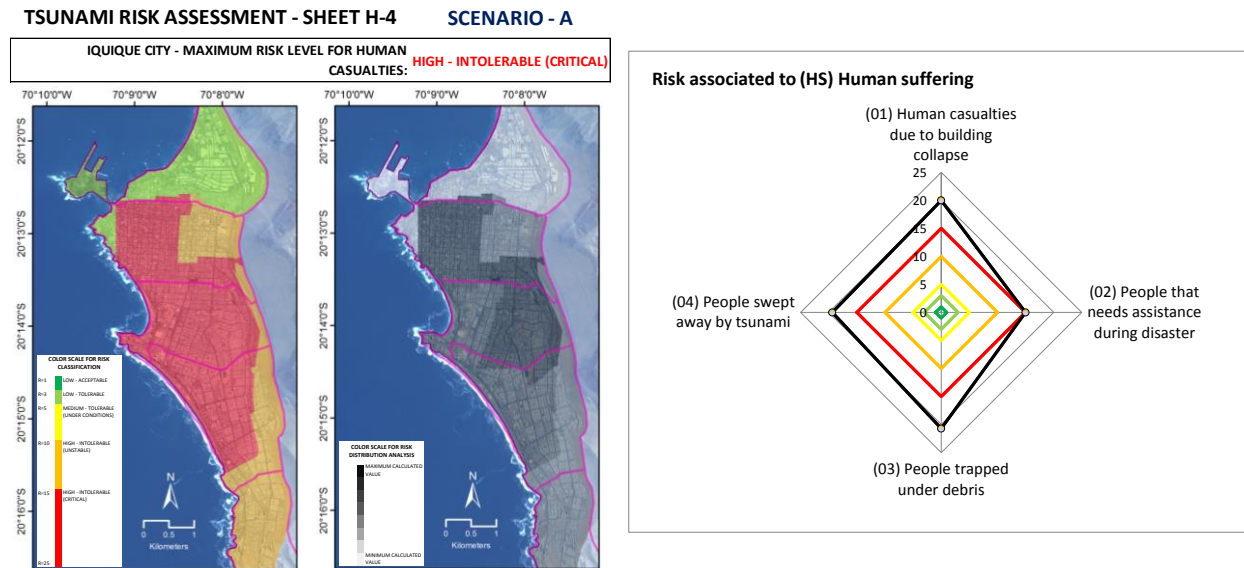


Figure 3. Example of tsunami disaster risk sheet.

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REFERENCES

- Municipalidad de Iquique, 2011. D.A.425 - Plan de Respuesta Comunal.
- PNUD, 2012. Análisis de Riesgos de Desastres en Chile, Santiago de Chile: United Nations Development Programme.
- SHOA, 2012. Iquique Carta de Inundación por Tsunami (3rd. Edition). Servicio Hidrográfico y Oceanográfico de la Armada de Chile.
- Yamaguchi Prefecture Earthquake Disaster Prevention Committee, 2008. Earthquake Damage Estimation in Yamaguchi Prefecture.