ANALYTIC HIERARCHY PROCESS: AN APPLICATION OF RISK PRIORITATION ASSESMENT FOR TOWNS UNDER NATURAL RISKS, IN AYSEN REGION - CHILE

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Summary: *Aysen Region, located at Chile's deep South, is characterized by natural geographical accidents that endow it of great scenic beauty. But in conjunction with cold and rainy weather, it also generates a source of important natural risks of geologic, hydrological, hydromorphologic and oceanographic nature, over the population that inhibits that southern Region.*

With AHP, an environmental vulnerability scale was built for the mostly exposed populated towns. The theoretical risk threshold was calculated and risk sensitive areas, which contain mostly exposed towns under the effects of an incident of natural origin, were identified. Risk monitoring and early alert plans were developed to prevent risks impacts over population. Alternative scenarios were considered to gauge the impact of different factors over sensitive areas definition.

Identifying sensitive areas is very important because it allows a more effective and efficient resource assignment process for setting monitoring and control plans over the Region.

1. Introduction

This study accomplished in Aysén Region, is based on the analysis of the natural processes that master or present a most or less periodical activity, which is currently translated into risks for the population's life located inside the influence area, and lose of their goods and private or state infrastructure, hindering regional development.

In this framework, the project "Natural Risks Detection Associated with the Human Accessions in Aysén Region and Proposal of an Early Alert System as Compared to Catastrophic Events", commissioned by the Regional Government, had as objective to deliver a vision of the natural processes in the Region that were capable of generating risks to their inhabitants and to accomplish a prioritization of the populated towns that present these risks and that therefore, make indispensable the generation of prevention programs and the application of emergency plans.

2. Risk Detection and Classification

A natural risk cartography was generated for each populated town in the Region, classifying risks according to their type as: geomorphologic, hydrologic, geologic or oceanographic ones. Later, localities were assessed according to their natural risks exposition level.

2.1 Risks Typology

a) Geological Risks
For the analysis of the geological risks at local level, the following variables were considered:

- Volcanic Ashes: located in their diffusion area of influence.

- Lahares: The territorial scope of the "lahares" was determined according to the regional historical precedents. The diffusion concept applied to the lahares was considered for the towns that could be affected under the coexistence of : Volcano - Glacier - Populated town
- Laves: All volcanoes with historical activity in the Region, (Hudson, Bruise Melimoyu, Cay, Mentolat and Puyuhuapi group) were considered.

b) Oceanographic Risks

- Tsunami Risk: It was considered for towns, in relation to their exposition or protection level to marine action. In the regional coasts, mostly depopulated, they have not experimented tsunami events or, at least, no historical records exist about it. The most important towns located in the coast are: Melinka (1.109 habitants in 1992 and 259 housings), located in the Ascension island in the Archipelago of Guaitecas and Port Aguirre (793 habitants in 1992 and 195 housings), located in The Huichas island in the Archipelago of Los Chonos. Most of the small fisherman coves are located at interior channels, so that in the event of a tsunami in the coast, its effect on human accessions would be mild or imperceptible.
- Seaquake Risk: Only the localities of Puerto Raúl Marín Balmaceda (327 habitants in 1992 and 107 housings) located in the gate of Palena river and Villa Melimoyu (89 habitants in 1992 and 33 housings), located in the bosom of the same name, present the risk to be affected by a seaquake due to their location in an unprotected position.

c) Geomorfological Risk

The geomorfological risk is referred to the incidence of dynamics of the natural processes that are produced in the hillsides, alluvial fan and in the pendulous lakes associated with ice fields. These processes correspond mainly to movements in bulk, specifically under the form of collapse, debris flow and alluvion wash. They were considered in the risks detection as processes joint. Types of risks were associated to:

- Debris flow and Collapse
- Rocky Material Contribution
- Alluvion wash
- Emptiness of lakes (alluvial flow of great magnitude associated with the collapse of a glacial lake. The washes alluvions are displaced through the water courses that act as emissaries).
- Current Torrential Action of Bankrupts: These bankrupts correspond to areas located in flanks of cones valley and banks in the influence area of the risk by alluvion. These riverbeds, even though they do not imply a danger by overflow, since well impacted channels and deepened in pending fort hillsides are present, carry risk by the deposit of considerable sedimentary loads of big size in sectors with loss of flow, associated with a slope change. Once the solid load is deposited waters down, these natural riverbeds acquire the category of flood risk by swellings of the bankrupts. Other case of occurrence of this type of risk is the corresponding to the type of characteristic bankrupts runoff and tidelands of great load capacity.

d) Hydrological Risk

This category considers the risks associated with fluvio-lacustrine behavior, expressed in floods; anegation and banks erosion.

Floods: In addition to the climatic condition that grants a certain temporality to the floods, was considered the presence of geoforms due to the erosion and deposit, that express the river dynamics in the landscape through different levels of terraces and types of beds. This concept implies that, the terrace as well as the beds are presented in sequence in a similar way, equal in morphogenesis but different in age, position and current dynamics, the one which can be very variable in the time and in the space, being in such a way considerate furthermore, as banal forms by their high mobility.

2.2 Risks Assessment

Prioritization of towns was based on risk assessment, so more exposed towns would have higher priority and would help to define sensitive areas.

Risk assessment was performed in absolute measurement form, delivering a final vulnerability index for natural risks for each town. Through the total risk function or Natural Risks Profile for the Region, the theoretical environmental risk threshold was calculated, so it was possible to emphasize those risks that surpassed the allowed threshold and consequently, identify the most exposed or vulnerable towns.

It is interesting to point out that it wss possible to decompose the Natural Risk Function in terms of it's strategic criteria. By doing this, mitigation measures could be generated in a more efficient way, since they would be concentrated in the contexts where the risks were meaningful.

3. AHP Model

Main components and results of the study, using AHP's terminology follows:

Modeling: From the analysis of natural risks for the populated centers, the risks hierarchy was built and relative weights derived.
Evaluation: During the risk assessment for each locality two scenarios related to volcanic aspects , were defined in order to perform a sensibility analysis over the results.

3.1 Modeling

3.1.1 Model Hierarchy

The risks model consists on a hierarchic structure defined for the defined global objective (GOAL) *"Evaluation and Prioritization of Natural Risks for the Populated towns of XI Region"* and presents a structure associated with the nature of the risks, according to the previously defined risk classification.

Figure 1 gives a view of the final model. It does not include absolute scales for terminal criteria.

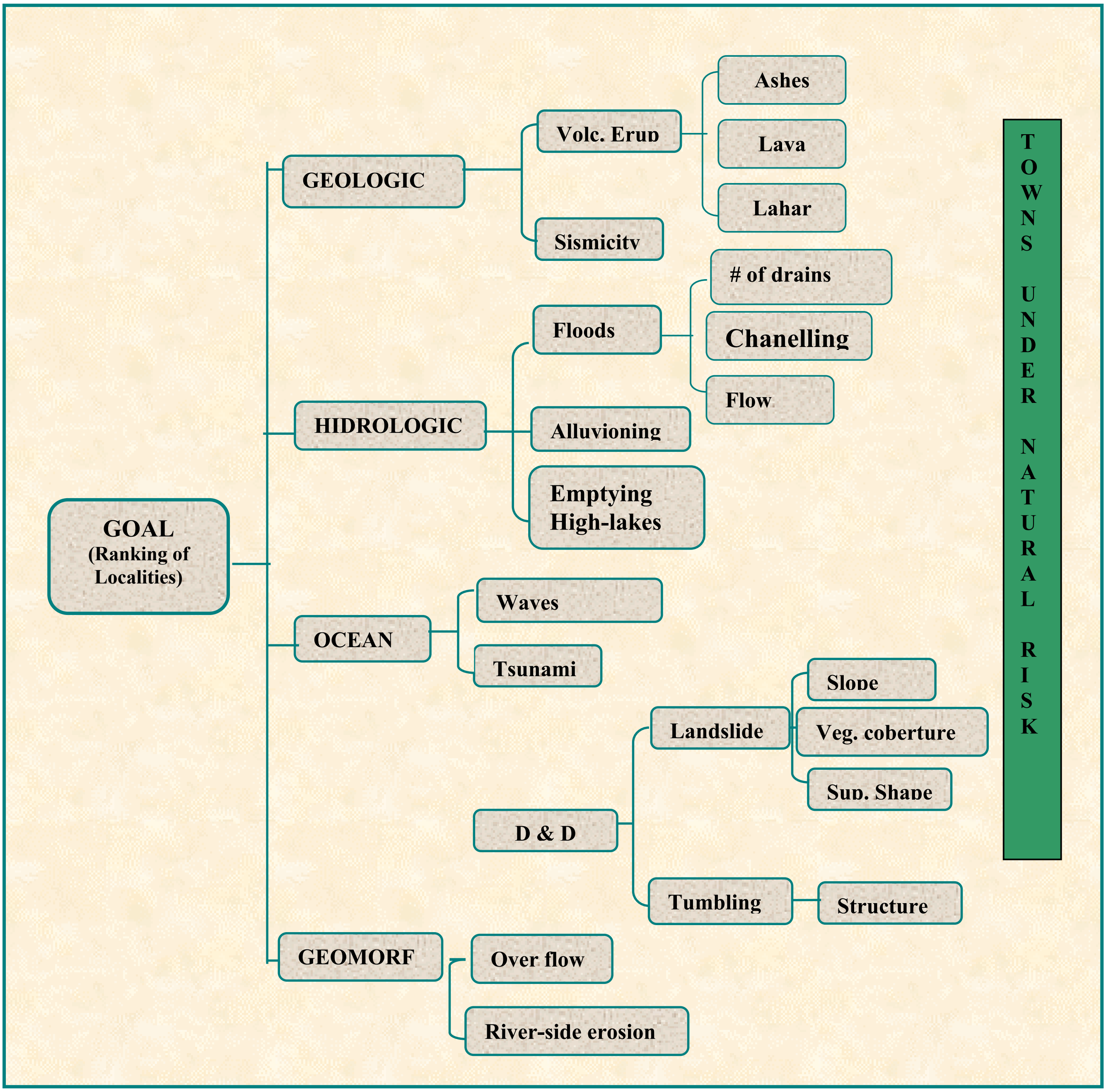

Figure 1. Natural risks hierarchy

3.1.2 Relative Importance (Weights) of the Strategic Criteria.

The natural risks hierarchy was generated and analyzed by a set of team work experts and by different regional authorities. For the calculation of the weights of the criteria, data gathered in the field visit, bibliography, existing studies of the zone, and personal interviews to different specialists and residents was incorporated.

Figure 2 graphically shows the relative importance of the global strategic risks for the Region. Bars reflect in proportional form, strategic risk weights distribution.

Abbreviation	Definition
Goal	Priorización de los Riesgos Naturales XI Región de Aysén
Geológic	Riesgos naturales de características geológicas
Hidrolog	Riesgos Naturales de caracteristicas Hidrológicas
Oceano	Riesgos Naturales de características oceánicas
Geomorfo	Riesgo por procesos geomorfologicos

Inconsistency Ratio =0.03

Figure 2. Global risks relative weights and the inconsistency ratio index

It is clear from Figure 2, that the main risk factor are the ones of geological origin in the Region (46,4%), surpassing the geomorfological risk which continues in importance with 31,1% of total weight.

It is interesting to point to out the different appraisal between specialists (vulcanologists skilled with regional volcanoes) and the local people, because the last ones considered the geological risk the smaller risk of the criteria group. This difference is explained due to the fact that persons submitted in permanent form to a certain risk, tend in time to lessen it or to ignore it. Due to the use of AHP model and the presence of specialists, these psychological reactions (normal for human beings), can be identified and explicitly incorporated to the model and its weights.

It is important to consider that hydrologic and geomorphologic risks, as very related and always present risks, add together 48,6% of total risk, surpassing slightly geological risk's weight . This consideration had as result the construction of 2 different evaluation scenarios:

- The previous model (base one)
- A scenario built by deleting the geological criterion from the model, so it is also called the "Scenario Without Geological Risk". This scenario, of course, is a virtual scenario, because the geological risk (even if explicitly ignored) does exist. But it is very useful since it allows an easy comparison with the base one and allows to evaluate more accurately the behavior of the other risk criteria.

3.1.3. Alternatives:
The last element of the model, are the alternatives to be evaluated. In this case they correspond to the set of 22 selected populated towns.

3.2 Evaluation

Since climate is an element that empowers natural risks, evaluation was performed under the "worst condition", i.e. : considering risk analysis and town evaluation under extreme climate conditions (high precipitation and/or wind).

4. Results

Given final town prioritization based on risks, it was possible to classify the evaluated towns according to their risk level, in acceptable risk localities (outside the sensitive area) and unacceptable risk localities (inside the sensitive area).

4.1 Towns Classification for the Scenario with Geological Risk

The quantitative values of the environmental risk index given by AHP were translated into a qualitative risk scale of intensity. This scale summarizes the vulnerability range in the following levels:

Low risk level	(Low vulnerability)	[0,000 - -> 0,107]
Moderate risk level	(Moderate Vulnerability)	[0,108 - -> 0,340]
High risk level	(High Vulnerability)	[0,341 - -> 1,000]

Figure 3: Theoretical break points levels

According to the above definition, the towns were sorted and classified as indicated in next Figure for the scenario with geological risk included.

Populated Towns	Assessment Value	Classification Risk
Melimoyu	0.463	High
Puyuhuapi	0.342	High
Cerro Villa Castillo	0.306	Moderate to High
Bay Murta|	0.270	Moderate
Port Ibañez|	0.260	Moderate
Port Aysén	0.241	Moderate
Port Saavedra	0.238	Moderate
Coyhaique	0.238	Moderate
Chile Chico	0.205	Moderate
Villa Mañihuales	0.165	Moderate
La Junta	0.163	Moderate
Port Rio Tranquilo	0.15	Moderate
Port Marín Balmaceda	0.149	Moderate
Villa O´HIGGINS	0.132	Moderate
Port Bertrand	0.108	Moderate to Low
El Blanco	0.084	Low
Port Guadal	0.081	Low
Ñireguao	0.080	Low
Melinka	0.044	Low
Port Aguirre	0.035	Low
Cochrane	0.031	Low
Tortel	0.028	Low
Break Point (Risk threshold)	0.341	
Global Inconsistency index	3%	

Figure 4. Towns ranking for scenario with geological risk

Figure 5 graphically shows the final ranking for this scenario.

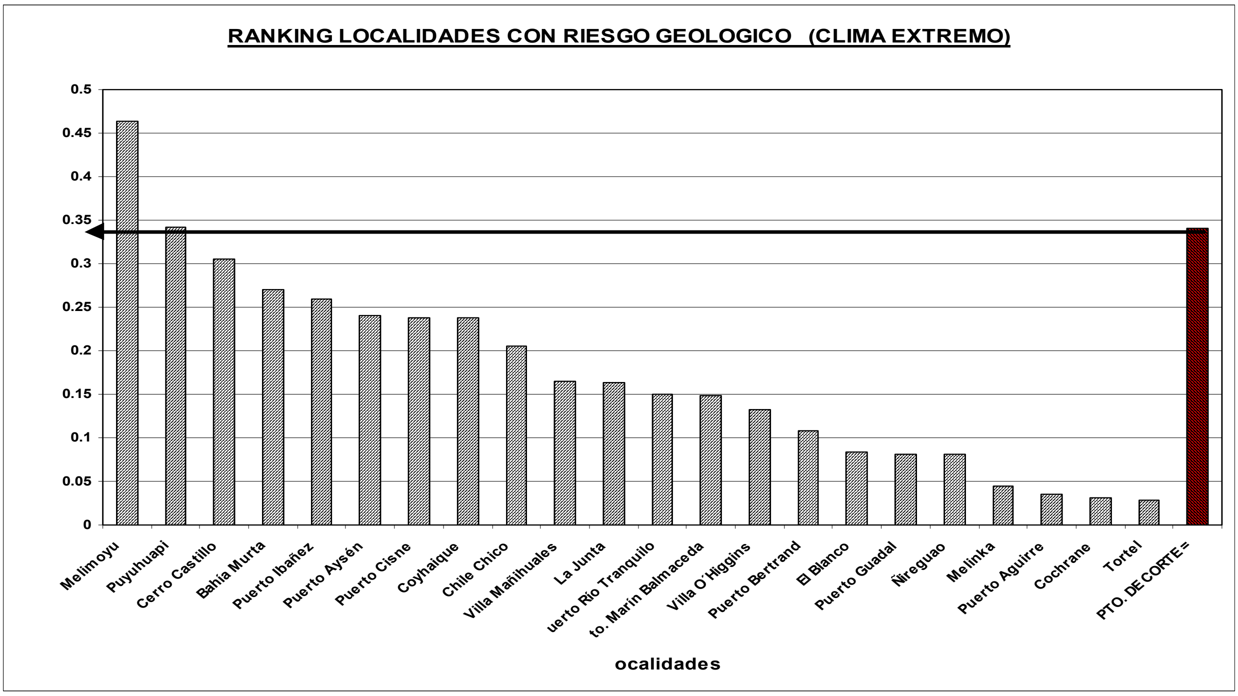

Figure 5. Graphical ranking for scenario with geological risk

In this scenario, 2 towns were classified with a high global risk: Melimoyu and Puyuhuapi, having both of them an absolute risk value above the acceptable value in a percentage of 36,0%, and 0,5 % respectively , due mainly to their exposition to the geological risks. (Red-black strip bar represents the break point for unacceptable absolute risks).

Villa Cerro Castillo presents a high moderate vulnerability with a value only 10,1% below the high global risk limit.

4.2 Towns Classification for the Scenario without Geological Risk (Virtual Scenario)

In this case, the town ranking is the following:

Populated Localities	Assessment Value	Classification Risk
Villa Cerro Castillo	0.45	High
Port Ibáñez	0.385	High
Coyhaique	0.375	High
Port Aysen	0.337	Moderate to High
Chile Chico	0.318	Moderate to High
Bay Murta	0.286	Moderate
Port Rio Tranquilo	0.253	Moderate
Villa Mañihuales	0.244	Moderate
Port Marín Balmaceda	0.232	Moderate
Villa O´HIGGINS	0.223	Moderate
Puyuhuapi	0.201	Moderate
Port Bertrand	0.196	Moderate
Port Saavedra	0.188	Moderate
La Junta	0.185	Moderate
Melimoyu	0.148	Moderate
Port Guadal	0.121	Moderate to Low
Ñireguao	0.098	Low

El Blanco	0.085	Low
Melinka	0.071	Low
Port Aguirre	0.056	Low
Cochrane	0.056	Low
Tortel	0.05	Low
Break Point (Risk threshold)	0.341	
Global Inconsistency index	3%	

Figure 6. Town ranking for scenario without geological risk

In this evaluation scenario, 3 towns with risk higher than the acceptable upper limit were identified: Villa Cerro Castillo, Puerto Ibáñez and Coyhaique, whose values surpass the threshold (break point) in 32,2%, 13,1%, 10,1% respectively.

It can be noted, that Villa Cerro Castillo, is classified as a high risk town for both considered scenarios.

Not considering geological risks, the towns of Puerto Aysen and Chile Chico were also included in the set of towns located in sensitive areas, due to their ranking levels (very much close to the threshold) and their (relative) high population and infrastructure conditions for the Region. So at the end, prioritization process was affected by natural risks for each locality, as well as by the factors of population and infrastructure.

4.3 Sensitive Areas Definition

Following Figure 7 compares towns classified with high or unacceptable risk level.

With Geological Risk (Real Scenario)		**Without Geological Risk (Virtual Scenario)**	
Towns	**Risk**	**Towns**	**Risk**
Melimoyu	0.4630	Villa Cerro Castillo	0.4500
Puyuhuapi	0.3420	Port Ibañez	0.3850
		Coyhaique	0.3750
		Port Aysén	0.3370

Figure 7. Sensitive risk towns set for both scenarios

5. Results Discussion

Following table and graphic show the final town vulnerability considering both scenarios. High or unacceptable risk situations are emphasized with bold font; towns with moderate risk have italic font while normal font is associated to low risk towns.

TOWNS	WITH GEO-RISK	WITHOUT GEO-RISK	DIFFERENCE
Melimoyu	**0.463**	*0.148*	- 68%
Puyuhuapi	**0.342**	*0.201*	- 41%
Villa Cerro Castillo	*0.306*	**0.450**	47%
Bay Murta	*0.270*	*0.286*	6%
Port Ibáñez	*0.260*	**0.385**	48%
Port Aysén	*0.241*	**0.337**	40%
Port Saavedra	*0.238*	*0.188*	- 21%
Coyhaique	*0.238*	**0.375**	58%
Chile Chico	*0.205*	**0.318**	55%
Villa Mañihuales	*0.165*	*0.244*	48%
La Junta	*0.163*	*0.185*	13%
Port Rio Tranquilo	*0.150*	*0.253*	69%
Puerto Marín Balmaceda	*0.149*	*0.232*	56%

Villa O´HIGGINS	*0.132*	*0.223*	69%
Port Bertrand	*0.108*	*0.196*	81%
El Blanco	0.084	0.085	1%
Port Guadal	0.081	0.121	49%
Ñireguao	0.08	0.098	23%
Melinka	0.044	0.071	61%
Port Aguirre	0.035	0.056	60%
Cochrane	0.031	0.056	81%
Tortel	0.028	0.05	79%

Figure 8. Comparison of town rankings for both scenarios

It is interesting to observe that in general terms, risk values are greater in the scenario without geological risk, (except for Melimoyu, Puyuhuapi, and Port Saavedra), something that was expectable, since those are the towns most exposed to risks of geological type. This is because in the scenario without geological risk, the hydrological and the geomorfological risks, increase their weight in a proportional manner.

It is important to point out that, even though in percentual terms the numerical difference delivered in the third column is high for some towns, in absolute terms the risk does not change dramatically going from one scenario to other. That means, no town changes its classification from low risk to high or viceversa.

In Figure 8, it may also be noticed that the 8 first towns of the list, present a level of high global risk, in at least one of the two evaluation scenarios, except for Bay Murta and Puerto Saavedra. This shows a high stability in the given solution set, and hence the reliability on the results of towns located in sensitive area, according to the given model.

Following Figure 9 shows the above in a graphically view.

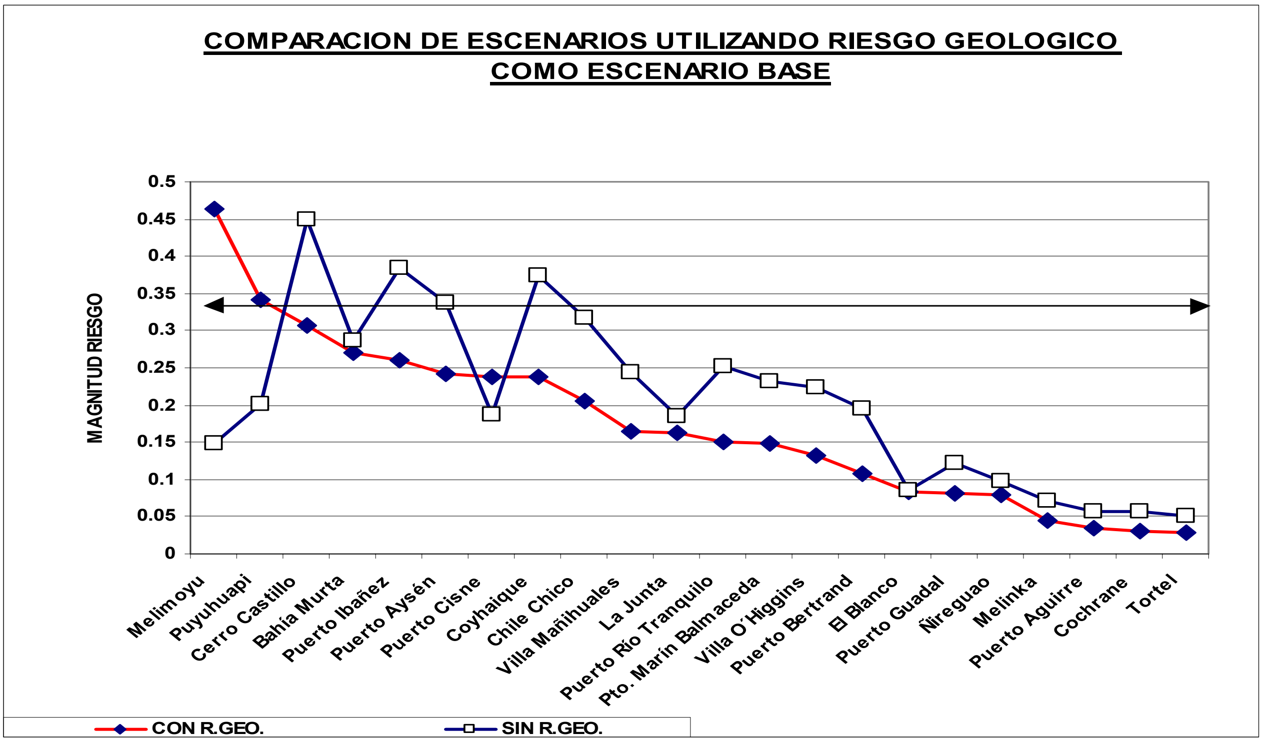

Figure 9: Scenarios comparison, using real scenario (with geological risk) as the basis

Main issues to outline from Figure 9 are the following:

- Curves represent the towns risk behaviors under each risk scenario assessment, in a normalized rating scale.
- The double arrow represents the break point (threshold) for the acceptable risk, for both evaluating scenarios.
- If a town risk level exceeds the break point level, then the town belongs to the sensible area set, not otherwise.
- Curves are quite similar for towns of low risk, (right side of the graphic), but no so much for the towns with high risk, the towns that belong to the sensitive area risk (left side of the graphic). This phenomenon is due to the fact that as we go more and more close to the graphic origin (which represents the North of Aysen Region), geological risks become more and more relevant (volcanic & sismic area), and that is exactly the difference between the two evaluation scenarios.

6. Main Benefits from the AHP Modeling Approach:

This approach gave the team the following possibilities:

- To define the emergency plans for natural catastrophes events just to the towns that belong to the sensible areas (defined mathematically by the break point model). Doing this, the efficacy in the objective solution is reached in a very optimal way.
- To optimize founds for resource allocations (the solution efficiency) through the cardinal priority ranking of towns (and its separate cardinal risk assessment for each town) building the efficient frontier curve.
- To define clearly (with dependence and cardinal values) each town's risk value and which is the main responsible risk criterion. Doing this, the design for emergency plans comes naturally for each town that belongs to the sensible area.
- To provide an easy to see and understand model that handles all relevant variables, regardless of their qualitative or quantitative nature.
- To stimulate and simplify participation of different kinds of actors, independent of their mathematical skill level.
- To build theoretical threshold for risk assessment from the model, both in a qualitative and quantitative way, define and classify, (i.e. give the ranges of what is understood for a high, moderate or low risk levels) the set of chosen towns in study.