# Environmental quality assessment in the coast of Concepción, Chile: application and comparative analysis for territorial planning

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## Abstract

This contribution is one of the results of the ELANEM Euro-Latin American project, INCO Programme, European Commission, and presents a procedure for sustainability assessment in coastal areas, based on a series of indicators and indices that reflect environmental quality. Indicators of pressure, state and response were obtained for the functions of naturalness, source of resources, sink, and human support services. Numerical indices are used to assess specific dimensions as well as integrated environmental quality. Special indicators were developed for geological hazard and risk processes. The validation of hazard geological processes was done using historical occurrence for floods and overflows; a mathematical model for tsunami and 3D models for landslides. Results obtained from thirty-two maps of environmental quality and of geological hazards are presented and discussed.
*Keywords: environmental quality, geological hazards, territorial planning.*

## 1 Introduction

Human activities and geologic-geomorphologic processes profoundly alter the coastal fringe. Processes such as tsunami, seismicity, landslides overflows and floods, influence the natural coastal evolution. Human actions, such as an improper administration of land planning produce rapid changes in coastal border. On the other hand, municipalities do not consider geological studies in

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the areas of urban and tourism development. For this reason, there occur constructions that are founded on faults, in zones of flood for tsunami and/or that can be affected by landslides. Therefore, the fragile equilibrium of coastal areas and associated environment become severely altered, causing a decrease of the quality of life and a dangerousness situation for the inhabitants.

It is thus convenient to design and apply procedures for determining and monitoring environmental quality. These procedures would help to analyse the evolution of the environment and assess to what extent that evolution is approaching or moving away from sustainability, Cendrero and Fischer [1], on the basis of clearly defined criteria and replicable methods. Spatial differences and temporal variation trends could thus be identified and response measures defined for improving the existing situation.

The whole studied area of Concepción region, central-south Chile, comprise five municipalities and 20 environmental units, which were defined and mapped on the basis of geological, geomorphological, hydrological, and land use features including hazards geological processes.

The methodological approach presented here was developed within the framework of the ELANEM Project, INCO Programme, European Commission.

## 2 Methodological approach

The concept of environmental quality is not easy to define and it is not exempt of subjectivity. To solve partly the subjectivity and to calculate the environmental quality index (EQI), measurable indicators were selected, particular criteria were implemented and a systematic and replicable procedure was established.

One criterion of environmental quality is the degree of preservation of natural characteristics: greater "naturalness" of an environmental or administrative unit represents higher quality of the considered unit. This criterion must be related with other functions and performs for human beings. It should somehow combine degree of naturalness (untouched character) of the unit assessed with its ability to perform as source of resources, sink of wastes and provider of support or services for human activities.

Environmental quality on the basis of criteria indicated above would represent an expression of the balance between preservation of nature, exploitation of its resources and use of its services. In principle, the better balance represents the more satisfactory performance of people-nature relationship.

The incorporation of the above mentioned criteria into an assessment procedure using measurable indicators reflecting significant characteristics related to them was established on the basis of Pressure-State-Response (P-S-R) framework, Mortensen [2], Jiménez Beltrán [3]. Accordingly, functions of naturalness (N), source of resources (R), sink of wastes (W), and human support and services (SS); types of interactions (P, S, R) and components represent the three dimensions of environmental quality that should be considered and incorporated into the selection of indicators for quality assessment.

Consequently, indices of pressure, state and response were obtained for the four environmental functions of naturalness (N), source of resources (R), sink of wastes (W), and human support and services (SS), applying: $INp = \Sigma Vi*Wi$, where INp = index of pressures on naturalness; Vi = normalized value of individual indicators; Wi = weight of individual indicators.

Irp = index of source of resources; Isp = index of sink of wastes; Issp = index of human support services were calculated in the same manner, as indices of state and response.

The indices of pressure, state, response for the different functions were then integrated into: IN = (INp + Ins +INr)/3, where IN = naturalness index; INp = pressure index; INs = state index; INr = response index.

The final environmental quality index (EQI) is the result of the relation between the indices naturalness (IN), source of resources (IR), sink of wastes (IW), and human support services (ISS): *EQI = (IN + IR + IW + ISS)/4*.

The EQI is dimensionless and cannot be interpreted as an absolute measure of environmental quality. Its increasing or decreasing index normalized (0 – 1) value will show if conditions are improving or getting worse.

The ELANEM approach uses administrative (municipalities) and natural units. The identification and the hierarchical subdivision of natural units was done on the basis of the combination of physiographic, geological, geomorphological, hydrological, surface processes and land cover/use characteristics. In this article EQI is related to administrative units.

The study and validation of hazard geological processes was done using historical occurrence for floods and overflows; mathematical model for tsunami and 3D models for landslides.

## 3 Environmental assessment

From all the studied functions, it is particularly interesting to present the results of the environmental quality index (EQI) obtained analyzing two sensitive indicators of pressure: water and solid urban wastes (RSU), as sink of residues function, in three coastal municipalities: San Pedro, Talcahuano and Penco, shown in fig. 1.

The concern of inhabitants about both indicators is different because the urban solid waste disposal sites may be observed, “smelled” and evaluated. Opposite situation is that related to drinkable water treatment.

In general, underground water, rivers and sea are the receptacle of urban and industrial wastes. The pollution of the main body water of the study area, the Bío Bío River, has a degree of pollution (nitrites and *Escherichia coli*) of about 90%. The secondary body water, Andalién River, has near the 26% of pollution. On the other hand, geochemical anomalies of heavy metals were found in marine sediments of the continental platform, Pineda *et al.* [4, 5].

Due to the fact that urban solid waste disposal sites (RSU) create visual and environmental contamination, there exists a main social and administrative concern about their management. San Pedro commune does not include waste disposal sites in its territory, in contrast of Talcahuano (dump closed in the middle of 2002) and Penco, which is, actually, the receptacle of the RSU of the neighbour’s municipalities.

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Figure 1: Location map.

Indices of indicators of pressure, state and response for the four human-environmental functions of naturalness, source of resources, sink and support and services are shown in table 1, considering water as sink function and table 2, considering solid wastes as sink function.

Table 1: EQI obtained considering water as sink function.

| | | Indicators | Penco index | Talcahuano index | San Pedro index |
|---|---|---|---|---|---|
| Naturalness | *Pressure* | Density of communications network | 0,73 | 0,73 | 0,57 |
| | *State* | Natural land cover | 0,17 | 0,06 | 0,01 |
| | *Response* | Protected area | 0,00 | 0,98 | 0,00 |
| Source | *Pressure* | Inhabitants related to II+III+IV class soil | 1,00 | 0,91 | 0,98 |
| | *State* | Cultivated area | 0,83 | 0,25 | 0,93 |
| | *Response* | Territory protected for farming use | 0,68 | 0,77 | 0,69 |
| Sink | *Pressure* | Annual water consumption | 0,95 | 0,11 | 0,84 |
| | *State* | Polluted river water | 0,74 | 0,00 | 0,50 |
| | *Response* | Municipality annual expenses on water treatment | 0,08 | 0,79 | 0,05 |
| Support & services | *Pressure* | Inhabitants density | 0,92 | 0,12 | 0,79 |
| | *State* | Area affected by natural hazards | 0,88 | 0,48 | 0,72 |
| | *Response* | Municipality annual expenses on hazard mitigation | 0,08 | 0,44 | 0,00 |
| | | EQI | 0,59 | 0,47 | 0,51 |

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Table 2: EQI obtained considering solid wastes as sink function.

| | | Indicators | Penco index | Talcahuano index | San Pedro index |
|---|---|---|---|---|---|
| Naturalness | *Pressure* | Density of communications network | 0,73 | 0,73 | 0,57 |
| | *State* | Natural land cover | 0,17 | 0,06 | 0,01 |
| | *Response* | Protected area | 0,00 | 0,98 | 0,00 |
| Source | *Pressure* | Inhabitants related to II+III+IV class soil | 1,00 | 0,91 | 0,98 |
| | *State* | Cultivated area | 0,83 | 0,25 | 0,93 |
| | *Response* | Territory protected for farming use | 0,68 | 0,77 | 0,69 |
| Sink | *Pressure* | Annual solid waste (RSU) per capita production | 0,99 | 0,08 | 0,85 |
| | *State* | Surface destined for solid waste (RSU) disposal | 0,96 | 0,93 | 1,00 |
| | *Response* | Municipality annual expenses on waste disposal | 0,06 | 0,45 | 0,50 |
| Support & Services | *Pressure* | Inhabitants density | 0,92 | 0,12 | 0,79 |
| | *State* | Area affected by natural hazards | 0,88 | 0,48 | 0,72 |
| | *Response* | Municipality annual expenses on hazard mitigation | 0,08 | 0,44 | 0,00 |
| | | EQI | 0,61 | 0,52 | 0,59 |

The analysis of Environmental Quality Index using only water indicator as a sink component shows a little variation of the general EQI index of the three municipalities (fig. 2).

Whereas, using urban solid waste disposal sites (RSU) as a single sink component the environmental quality index shows a different value in comparison to the general EQI index (fig. 3).

The EQI index obtained using urban solid waste disposal sites (RSU) shows the really environmental estimation of the inhabitants of this study area.

The minor EQI index of Talcahuano municipality is due to the production of the major quantity of urban residues/per capita/year.

The EQI index of San Pedro municipality suggests the foremost expenses in transport of urban residues.

The higher EQI index of Penco municipality is expected because this administrative area receives high economic benefits for the reception of urban solid wastes from the other municipalities.

However, the societal pressure to avoid site disposal wastes is very strong.

The management of both indicators, by the local administrative organizations, is not harmonious, favouring the treatment of the urban waste on top of the served urban waters and industrial liquid residues.

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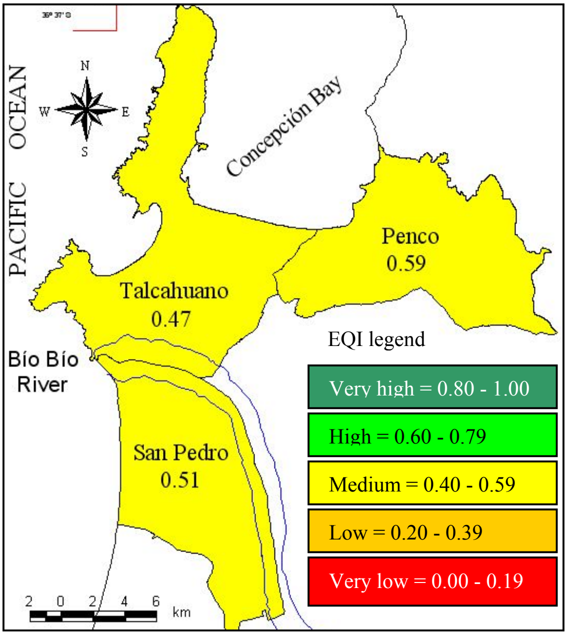


Figure 2: EQI considering water as sink function.

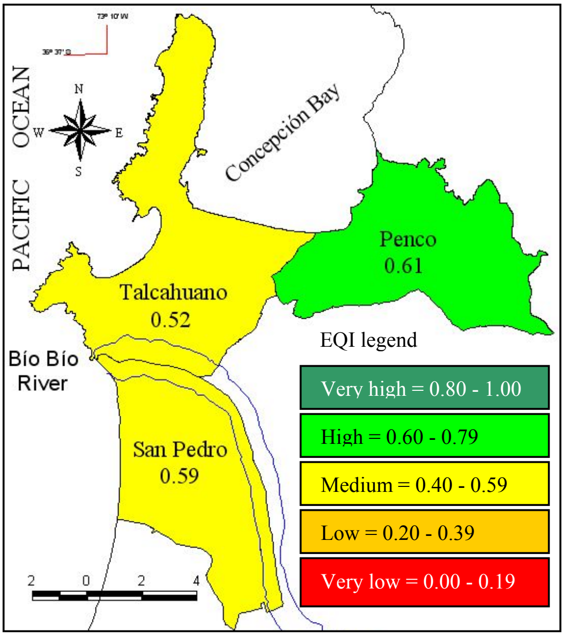


Figure 3: EQI considering wastes as sink function.

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# 4 Hazardness

Tsunami, seismicity and mass movements are the main geological hazardness processes (fig. 4). Seismic is an unconfined territorial hazard. In contrast, for tsunami and landslides processes the area of influence can be determined, Cecioni *et al.* [6, 7].

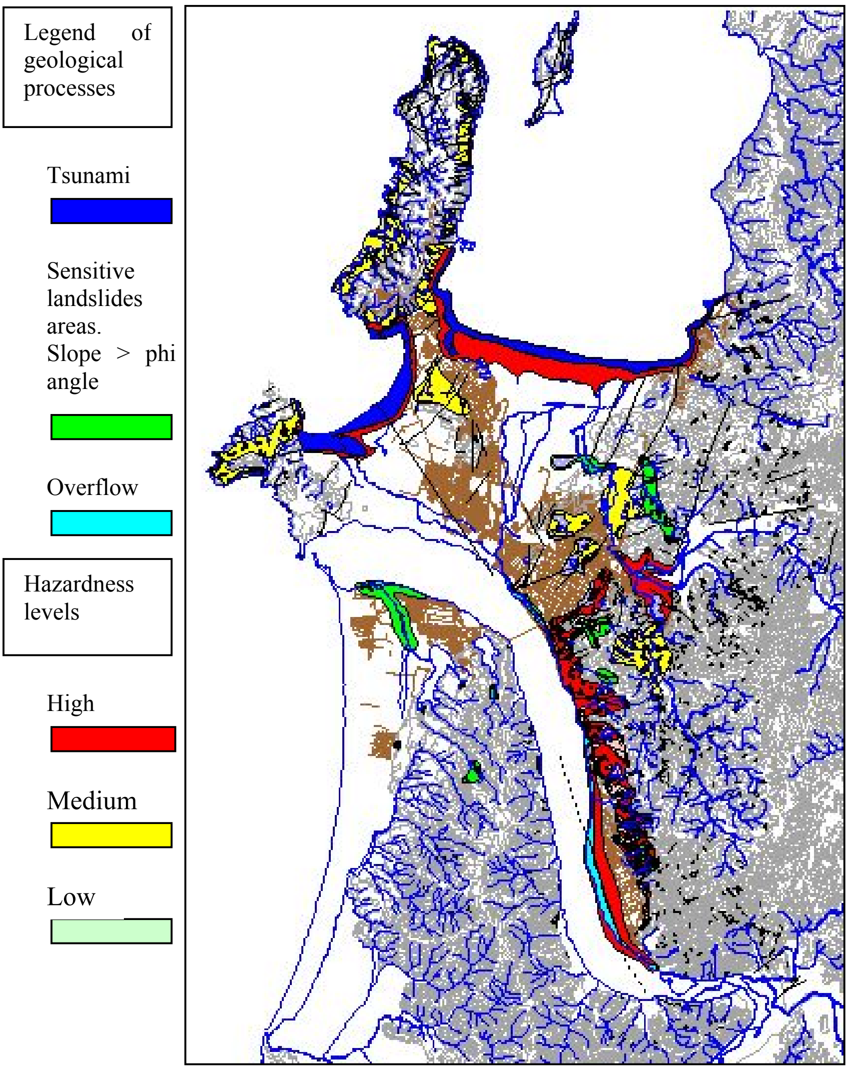
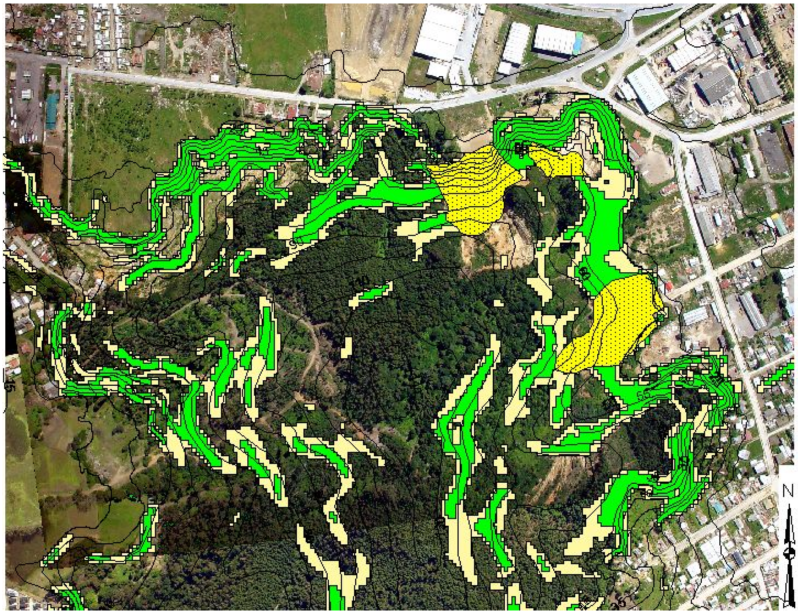



Figure 4: Area of influence of geological processes and hazardness zones.




Legend:

| | |
|---|---|
| | Occurred landslides in predicted areas |
| | Model considering slope between 61%-81% |
| | Model considering slope between 81%-100% |

Figure 5: Landslides sensitive areas and occurred landslides.

For landslides evaluation slope angle and phi angle (triaxial method) of materials were obtained and a simple digital model was applied in areas of landslides hazardness, analyzing the relation between slope and phi angles. During the winter season of 2002, landslides occurred just in the areas in which slope angle was higher than phi angle. Fig. 5 obtained from 3D aerial photograph, shows potential areas of mass movements and the occurrence of landslides, especially in zones were the forested cover was removed without construction for slopes protecting.

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## 5 Conclusions

The environmental quality index (EQI) is congruent with the really estimation of each municipality and the areas of influence of geological hazardness processes are well delimited in the environmental unit. It is natural to suppose that more work is needed, specially a systematic validation and sensitivity analyses. Nevertheless, the results obtained suggest that the method is strong enough to provide meaningful classifications of environmental quality, even if relatively different indicator sets are used.

The ELANEM project permitted to accurate the zoning of the most dangerous geological processes, which will allow the authorities to establish the preventive measurements adapted to avoid damages to the population and to think about the utility of geology as an essential tool for territorial planning.

This study is a first estimation for the evaluation of the environmental quality, and another of the main results is the very useful and recognized integration of public administration, private industry, social perception and university, in one common objective: sustainable progress and better quality of life.

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