RISK-BASED MODEL FOR PRIORITIZATION OF ENVIRONMENTAL INSPECTIONS IN CHILE

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Risk-based Model for Prioritization of Environmental Inspections in Chile

Contents

Introduction: Context and Motivation

- In Chile, the recently modified (2011) environmental law created the Superintendence of the Environment (SOE).
- One of the SOE´s main objectives is to inspect the compliance of all projects or activities with environmental permits (> 12,000)
- The SOE´s task force has a current capacity to inspect approximately 1,000 sites yearly.

→ There is a strong need to prioritize inspection efforts

Current Practice

- OECD and Latin American countries´ risk estimation methodologies used for different purposes (licensing, prioritization, etc.) were reviewed
- The most comprehensive, UK´s OPRA (Operational Risk Appraisal), considers the following attributes to profile a site:
  - Installation complexity
  - Emissions and inputs
  - Location
  - Operator performance
  - Compliance rating
- The site profile is used to:
  - Plan use of resources
  - Report the performance on the regulated sites
  - Define charges for permits

Method: A simple equation for risk estimation

The objective risk of the activity **A** associated with the release of a primary pollutant **P** that affects a receptor **R**, through a secondary pollutant **C**, is given by:

$$Risk_{C,A}^{P,R} = UR_C^R\left[\frac{R}{ppm}\right] \cdot AL_A\left[\frac{act}{day}\right] \cdot EF_A^P\left[\frac{g}{act}\right] \cdot ECF_C^P\left[\frac{ppm}{g/day}\right] \cdot Pop_C^R[p]$$

Risk Agent

Project or activity

Surrounding environment

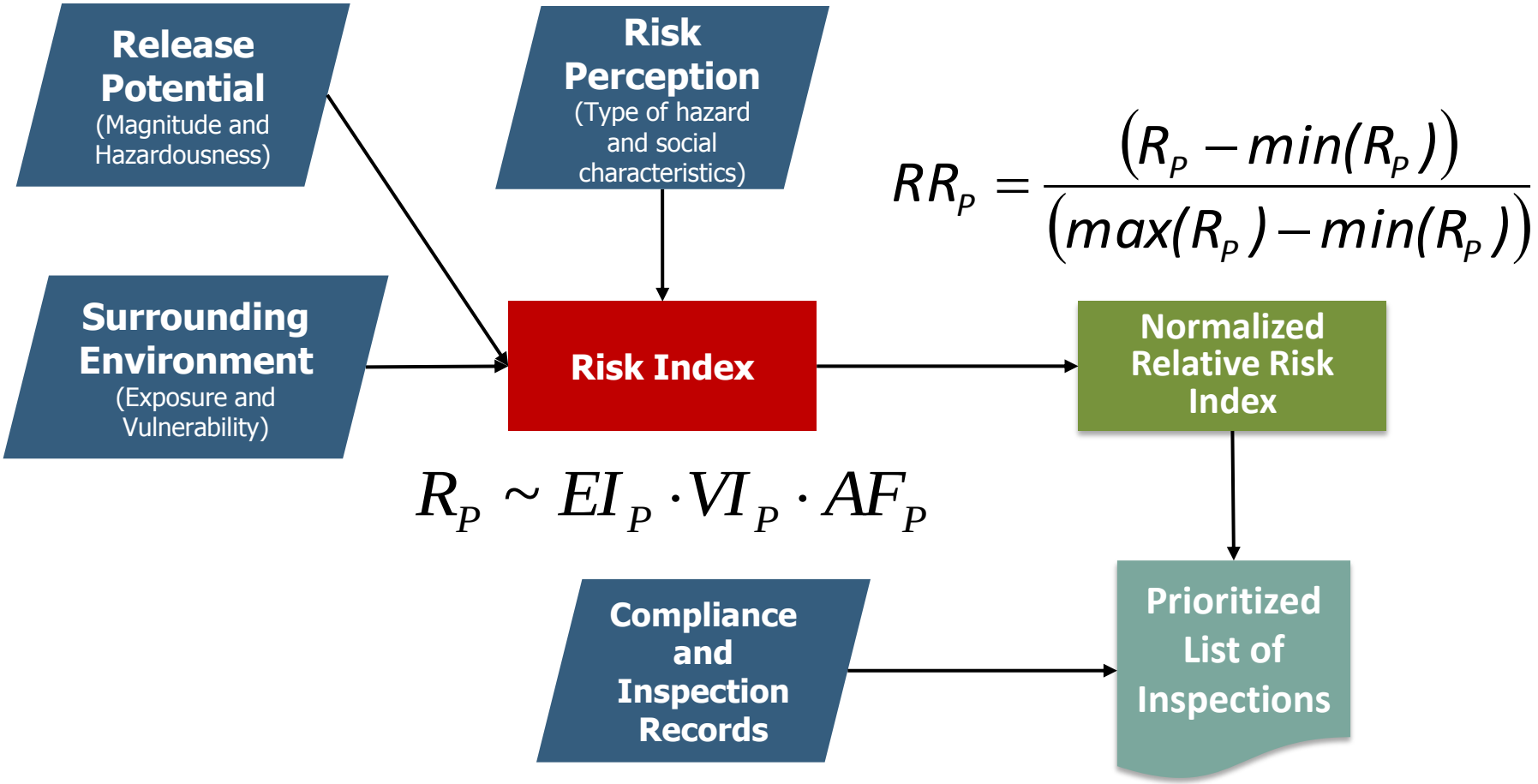
where:

- UR: Unitary Risk
- AL: Activity Level
- EF: Emission Factor
- ECF: Emission-Concentration Factor
- Pop: Population
- P: primary pollutant
- C: secondary pollutant
- R: receptor
- A: activity

Method

- In practice, it is impossible (or extremely difficult) to estimate the risk for each of the more than 12,000 activities or projects with environmental permits.
- There are information gaps from a work in progress environmental information system.
- To do this, an approximate model that considers the characteristics of each activity or project and characteristics of the surrounding environment, was developed.
- The model considers:
  - Project characteristics
  - Geographic and demographic variables
  - Identified environmental components
  - Data from the compliance and inspection records

Framework for Environmental Inspections Prioritization in Chile



Release Potential Index

- **This index represents the release potential of risk agents to the environment**
- Types considered:
  - Air Emissions
  - Water Discharges
  - Discharges onto the Sewage System
  - Waste Generation

- The index considers two dimensions:
  - **Magnitude** of the release
  - **Hazardousness** of the risk agent released

- Three adjustments ("punishments") are made, according to:
  - Baseline Environmental Quality
  - Environmental Monitoring
  - Non-compliance Records

Release Potential Index Estimation

1. **Magnitude** of release of risk agent **c** into medium **m** by project/activity **i:**

$$Release^{i}_{c,m}$$

2. The **magnitude** of release (or potential release) is expanded by the three adjustments:

$$Final\_Release^{i}_{c,m} = Release^{i}_{c,m} \cdot W_{BLEQ} \cdot W_{Mon} \cdot W_{NCR}$$

3. The **hazardousness** of the released risk agent **c** onto the medium **m**

$$Hazardousness_{c,m} \approx \frac{1}{Threshold_{c,m}}$$

4. The release potential index is estimated as:

$$I_{RE} = Final\_Release^{i}_{m} \times Hazardousness_{c,m} \approx \frac{Final\_Release^{i}_{m}}{Threshold_{c,m}}$$

Relase Potential Index Adjustments

Baseline Environmental Quality

If the baseline env. quality is:	W(BEQ)
Compliant	1.0
Latent Zone	1.1
Saturated Zone	1.3
EPP or EDP Zone	1.5

Environmental Monitoring

If the Environmental Monitoring has detected:	W(Mon)
Nothing	1.0
Non-compliance through Social Monitoring	1.3
Non-compliance through Env. Quality Stations	1.5

Non-compliance Records

If the non-compliance records show:	W(NCR)
With no sanction nor admonition	1.0
Admonition or warning	1.1
< USD 18,500	1.2 – 1.3
> USD 18,500	1.3 – 1.5

Surrounding Environment Index

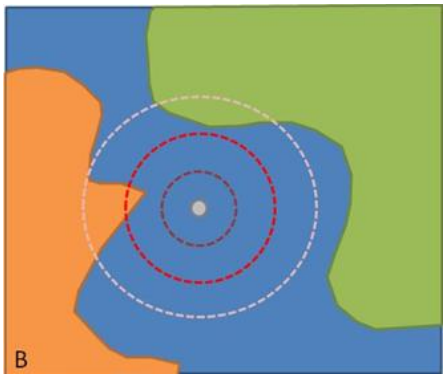
- This index has the objective of characterizing the surrounding environment of each project, focusing on the following receptors:
  - Human Population
  - Ecosystems (Natural Resources)
  - Cultural Heritage
- 3 buffers representing different influence areas are considered:
  - 250 m
  - 1,000 m
  - 4,000 m
- It is constructed based on the following dimensions:
  - Vulnerability
  - Exposure

Receptors considered - details

Human Population	Ecosystems	Cultural Heritage
• Urban • Rural	• Protected Areas SNASPE • Private Protected Areas • Natural Sanctuaries • RAMSAR Sites • Bodies of water • Native Forests • Protected Marine Coastal Areas • Protected Aquifers and Lowlands • Priority Sites for Biodiversity conservation	• National monuments • Indigenous Reserve and Development Areas • Touristic interest sites • Historic/scientific interest Areas

Exposure Estimation

- For each receptor, if there are elements contained within each buffer, a score will be activated:



Proximity (m)	Score
<250	10
250 – 1,000	6
1,000– 4,000	1

- The exposure variable is a 3X3 matrix: 3 receptors vs. 3 buffer

Elements contained within the buffer?			
Receptor	*Buffer*		
	250	1,000	4,000
Human Population	yes	yes	yes
Ecosystems	no	yes	no
Cultural heritage	no	no	yes

→

Score for exposure sub-index			
Receptor	*Buffer*		
	250	1,000	4,000
Human population	10	6	1
Ecosystems	0	6	0
Cultural heritage	0	0	1

Vulnerability: How is it considered?

- Human Population:
  - size of potentially exposed population
  - characteristics of potentially exposed population:
    - age
    - socio-economic status
- Ecosystems and Cultural Heritage
  - Number of potentially exposed elements
  - (*characteristics of exposed elements*)

Vulnerability Estimation

- For each buffer and receptor scores are assigned according to the vulnerability of the receptor:
  - Human Population:

Age Group		Socioeconomic group		
		Indigent	Poor	Non-poor
		3	2	1
Under-age	1	3	2	1
Adults	1	3	2	1
Elders	2	6	4	2

$$Vuln = Pop \times AS$$

  - Ecosystems and Cultural Heritage:
    - neutral scores of 1, due to the lack of information concerning the relative vulnerability of the different sensitive layers of information used

$$Vuln = Elem \times AS \approx Elem \times 1$$

Surrounding Environment Index – Estimation

1) Surrounding Environment Score (SES):

$$SES^R = Exp^R \times Vuln^R$$

2) Normalization of SES (NSES):

$$NSES^R = \frac{\left(SES^R - min(SES^R)\right)}{\left(max(SES^R) - min(SES^R)\right)} \cdot \left(100 - 1\right) + 1$$

3) Surrounding Environment Index (SEI):

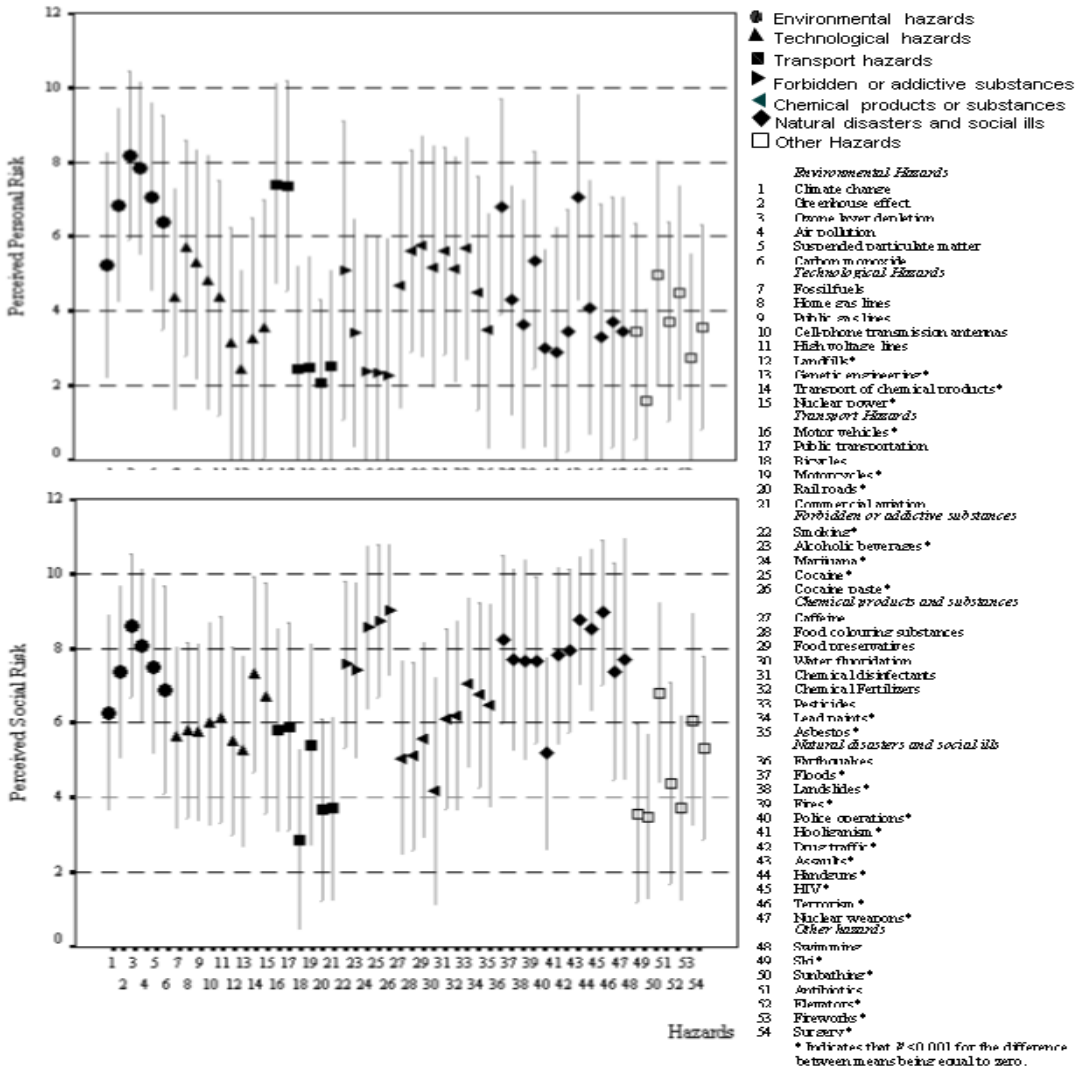
$$I_{SE}^i = \frac{1}{3} \cdot \left(NSES^{Population} + NSES^{Ecosystems} + NSES^{CulturalHeritage}\right)$$

Risk Perception Index

Bronfman, N. and L. A. Cifuentes (2003). "Risk Perception in a Developing Country: The Case of Chile." *RiskAnalysis 6(3): 1309-1323.*

- A survey was conducted to 508 residents in Santiago, Chile.
- The survey included 54 hazards, 16 risk attributes, and 3 risk constructs.
- Perceived risk scores were estimated for each of the 54 hazards:
  - Enviromental Hazards
  - Technological Hazards
  - Forbidden or addictive substances
  - Chemical products and substances
  - Natural disasters and social ills

Risk Perception Scores



Source: Bronfman and Cifuentes (2003)

Risk Perception Index Estimation

1) Risk scores related to **environmental hazards** are normalized for an average risk score of 1

$$NRS^h = \frac{RS^h}{\underset{h}{average}\left(RS^h\right)}$$

2) For each type of project, the risk perception index is obtained as the maximum normalized risk score for all associated hazards

The project types with average social risk score obtain an index value of 1 (neutral)

Compliance and Inspection Records Adjustment

- Through the Compliance and Inspection Records, an adjustment to the order of priorities is made, depending on the time that has elapsed since the last Inspection:

Time since the last Inspection (years)	CIR Adjustment
1	1.0
2	1.1
>=3	1.2

Relative Environmental Risk Estimation

1) Perceived Risk Index (PRI) is estimated as the product of:
   - Release Potential Index
   - Surrounding Environment Index
   - Risk Perception Index

$$PRI^i = I^i_{RE} \cdot I^i_{SE} \cdot I^i_{RP}$$

2) Then, the PRI value is normalized for a minimum of 1 and maximum of 100.
3) The final score to obtain the listing for environmental inspections:

$$RER^i = PRI^i \cdot CIR\_Adj^i$$

Data

- Data was obtained from:
  - Projects:
    - SEA (environmental assessment system)
    - RETC (pollutant release and transfer register)
  - Environmental Monitoring:
    - national environmental monitoring network
  - Environmental Components:
    - GIS layers of ecosistemic and cultural heritage
    - National population census
    - National health survey

Imputation of missing data

- In order for the risk model to work properly, it is important to estimate the risk of all sources (since it is a relative risk model).
- For any index, if there is no data, it is necessary to fill in data points using the best available information.
- In general, the following protocol for data imputation is used:
  1. Real data
  2. Regulation data (e.g. emission standards)
  3. Generic data that characterizes the specific industrial sector or surrounding environment
- The results of the assessment are refined automatically when the quality of information available is improved.

Quick Example

Release Score Estimation - Example

Site	Pollutant	Real Emissions	Permitted Emissions		Average Emissions by CIIU	Final Releases
			Source	Sector		
		(kg/year)				(kg/year)
1	PM2.5	**1.000**	1.500	1.800	1.800	**1.000**
	NOX	**Doesn't Emit**	20.000	25.000	27.000	**0**
	SOX	**40.000**	10.000	15.000	18.000	**40.000**
2	PM2.5	N/A	**1.500**	**1.800**	2.000	**1.800**
	NOX	N/A	**20.000**	**25.000**	30.000	**25.000**
	SOX	N/A	**10.000**	**15.000**	20.000	**15.000**
3	PM2.5	N/A	N/A	N/A	**2.200**	**2.200**
	NOX	N/A	N/A	N/A	**33.000**	**33.000**
	SOX	N/A	N/A	N/A	**22.000**	**22.000**

Release Index Estimation - Example

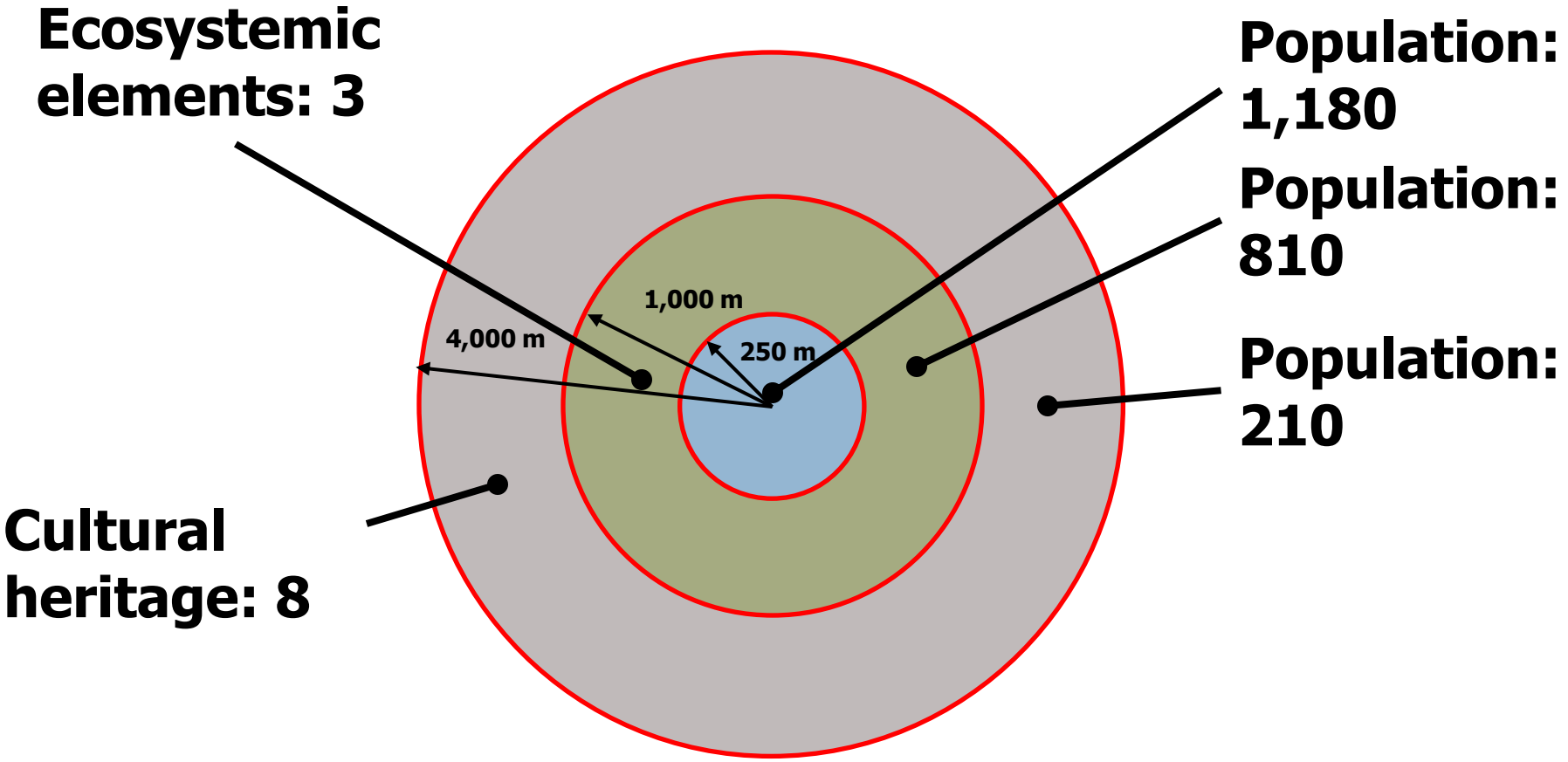
- Assuming that no adjustment has to be done relating baseline environmental quality, environmental monitoring and non-compliance records:

Site	Pollutant	Release (kg/year)	Threshold* (kg/year)	Score (Rel/Thresh)	Score on Aire Releases	Release Potential Index
1	PM2.5	1,000	20,000	0.05	**1.32**	**1**
	NOX	0	100,000	0		
	SOX	40,000	150,000	0.27		
2	PM2.5	1,800	200,00	0.09	**1.44**	**46**
	NOX	25,000	100,000	0.25		
	SOX	15,000	150,000	0.1		
3	PM2.5	2,200	20,000	0.11	**1.59**	**100**
	NOX	33,000	100,000	0.33		
	SOX	22,000	150,000	0.15		

*Source: EU-PARLIAMENT and EU-COUNCIL 2006. European Pollutant Release and Transfer Register

- Aggregate Score= 1 + sum(p, c)

Exposed Population and Environmental Elements - Example



Exposure Estimation - Example

	Elements contained within the buffer?		
Receptor	*Buffer*		
	250	1,000	4,000
Human Population	yes	yes	yes
Ecosystems	no	yes	no
Cultural heritage	no	no	yes

→

Score table	***Score for exposure sub-index***		
Receptor	*Buffer*		
	250	1000	4000
Human population	10	6	1
Ecosystems	0	6	0
Cultural heritage	0	0	1

Vulnerability Estimation for Human Population - Example

Human group		*Adjustment score*	*Nº of people within the buffer*				*De-aggregated Score for vulnerability sub-index*		
			Buffer				*Buffer*		
			250	**1,000**	**4,000**		**250**	**1,000**	**4,000**
Under-aged	Non-poor	**1**	60	40	10		60	40	10
	Poor	**2**	100	50	20		200	100	40
	Indigent	**3**	20	10	5	->	60	30	15
Adults	Non-poor	**1**	240	140	30		240	140	30
	Poor	**2**	400	300	50		800	600	100
	Indigent	**3**	100	50	10		300	150	30
Elders	Non-poor	**2**	70	80	30		140	160	60
	Poor	**4**	130	115	40		520	460	160
	Indigent	**6**	60	25	15		360	150	90
						Final Score for Vulnerability Sub-index	**2,680**	**1,830**	**535**

$$Vuln = Pop \times AS$$

Vulnerability of Ecosystems and Cultural Heritage - Example

Receptor	*Sensible Element Type*	*Adjustment Score*	Elements within the buffer				*Final score for vulnerability sub-index*		
			Buffer				*Buffer*		
			250	**1,000**	**4,000**		**250**	**1,000**	**4,000**
Ecosystems	Type 1	**1**	0	0	0	→	0	3	0
	Type 2	**1**	0	2	0				
	Type 3	**1**	0	1	0				
	Type 4	**1**	0	0	0				
Cultural Heritage	Type 1	**1**	0	0	0	→	0	0	8
	Type 2	**1**	0	0	5				
	Type 3	**1**	0	0	3				
	Type 4	**1**	0	0	0				

$$Vuln = Elem \times AS \approx Elem \times 1$$

Surrounding Environment Index - Example

1. The Surrounding Environment Score is given by the weighted sum of the exposure and vulnerability sub-indexes, aggregated for the three *buffers*

Receptor	Exposure			Vulnerability			SE Score
	250	1,000	4,000	250	1,000	4,000	
Human population	10	6	1	2,680	1,830	535	**38,315**
Ecosystems	0	6	0	0	3	0	**18**
Cultural Heritage	0	0	1	0	0	8	**8**

2. The Normalized Surrounding Environment Score takes into account the maximum and minimum SES´s of the universe of projects.
3. The Surrounding Environment Index is given by the average score of the three receptors:

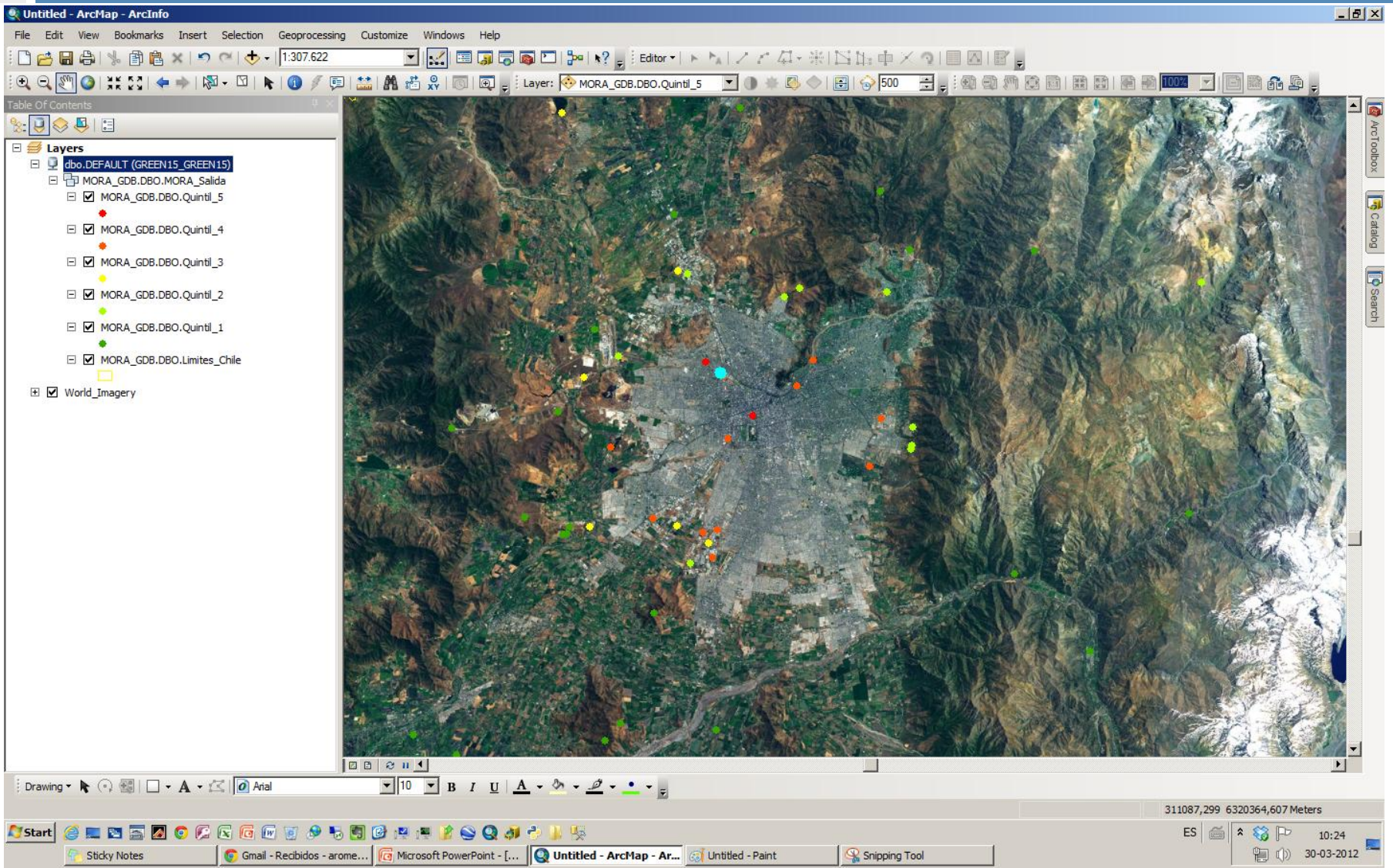
Receptor	SES	Minimum SES	Maximum SES	Normalized SES (1-100)	SE Index (1-100)
Human Population	38,315	1,000	118,000	32.6	32.9
Ecosystems	18	1	32	55.3	
Cultural Heritage	8	5	35	10.9	

Relative Risk Index - Example

- Assuming risk perception index values of 1, 1.06 and 0.7 for the 3 sites respectively:

Site	Release Index	Surrounding Environment Index	Relative Risk	Risk Perception Index	Perceived Relative Risk	Normalized Relative Risk
1	1	32.9	32.9	1	32.9	**1**
2	46	32.9	1,513	1.06	1,604	**70**
3	100	32.9	3,290	0.7	2,303	**100**

Results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Layers
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MORA_GDB.DBO.Quintil_5
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Conclusions

- The challenge of estimating the relative risk of 12 thousand projects is not trivial (only finding the required information for these projects is a large task).
- The model presented here pretends to rank projects in the best way possible, considering the best available information.
- Considering the cases studied, this model is pioneer in the use of geographical information to prioritize inspection of industrial sites.
- The model represents the first objective and non-discretional approach of the difficult task of prioritization of inspections in Chile.
- The algorithm has weaknesses and is open for improvements once the first rounds of prioritization are done.

Contributors

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- Carolina Vera

THANK YOU!

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