Geoindicators for evaluating geological impact on Brazilian urban areas

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Abstract: Geoindicators provide a technique for identification and analysis of geological impact on urban areas. This technique has been set down in Brazilian Law since 2001. The impacts are partly related to physical environment attributes concerning soil, rock and groundwater. In order to establish a rapid appraisal of neighbourhood impact recognition, a number of geoindicators are proposed and their classes and relative importance determined. The methodology proposes impact identification and evaluation based on an impact matrix (SPRING 4.1, Brazilian SIG). In order to test the effectiveness of the methodology, testing has involved twenty different industrial concerns from São Carlos Science Park (Pólo Tecnológico de São Carlos), and has been shown to provide a planning basis for locating new industrial developments.

Résumé: Le voisinage enfonce de l'identification et l'analyse est une technique pour étude des impacts de l'environnement dans les régions urbaines au Brésil. Cette technique a été prévue dans loi brésilienne depuis 2001 et peut impliquer des plusieurs genres d'occupations urbaines. Partie des impacts considérée est en rapport avec les attributs de l'environnement physiques, en impliquant sol, roc et groundwater. Pour établir une estimation rapide de reconnaissance de l'impact du voisinage le papier propose plusieurs geoindicators, ajusté de geoindicators traditionnel, être inspecté en réponse à lois brésiliennes. Les impacts de voisinage ont été décrits et leurs classes et importance relative ont déterminé. La méthodologie propose identification de l'impact et évaluation basées sur un processus de la matrice de l'impact rendu effectif au PRINTEMPS 4.1 (SIG brésilien). Tous les impacts considérés ont été observés, en ayant leur influence relative mesuré, et a évalué basé sur classification de l'impact. Pour tester l'efficacité de la méthodologie, une épreuve qui implique vingt industries différentes de São Carlos Science Parc (Pólo Tecnológico de São Carlos) a été mené avec genres différents d'activité industrielle. Les résultats montrent que ce groupe d'impacts urbains peut être évalué utiliser la technologie GIS facilement et son identification fournit l'information de base pour localiser la nouvelle industrie dans urbanisme brésilien.

Keywords: environmental impact, urban geoscience, planning, environmental geology, mass movement, erosion.

INTRODUCTION

The term *Neighbourhood Impact* is a term used to describe a specific group of environmental impacts that occur in urban areas as a consequence of new construction works. To evaluate such impact, there is a need to reveal the character of the proposed works, its area of influence, and consider mitigation or compensation measures.

Within Brazil there is a tendency in neighbourhood impact studies to considering mainly the impacts on urban infrastructure; relatively little emphasis is placed on impact on the natural environment.

Here it is proposed that geoindicators be adopted as the basis for survey neighbourhood impact, utilising the impact matrix.

NEIGHBOURHOOD IMPACT STUDIES

Origins and Concept

Goldner (1996) discussed the characterisation of environmental impacts due to construction in Brazil, mainly in terms of urban road systems. Ribeiro & Falcoski (1998) proposed the concept of environmental performance as a tool for urban impact evaluation.

Brandão *et al*. (2001) proposed a utilisation coefficient to characterise urban development. Crepaldi (2003) considered urban impact as the basis for guidelines for urban planning in relation to ground conditions.

Law 10.257/2001 (Brazil, 2001) proposed the use of neighbourhood impact studies. For example, in São Paulo Moreira (1997) described the necessity of neighbourhood impact studies to justify new urban infrastructure construction. Santoro & Nunes (2003) describe Porto Alegre in similar fashion. Campo Grande has Town Planning Guidelines (Cymbalista, 2001), which define urban road system alterations.

Developing a neighbourhood impact study requires identification of the proposed land usage and its repercussions on the urban environment, including human activity and natural resources. The steps that must be considered are: (1) enterprise characterisation; (2) neighbourhood characterisation; (3) impact identification and evaluation.

Legal Basis

The aim of Law 10.257/2001 was to regulate Articles 182 and 183 of the Brazilian Constitution. The neighbourhood impact study was instituted in Articles 36 to 38 of the Law. Article 36 defines that the municipality must be responsible for determining which enterprises or activities must be approved in terms of a neighbourhood impact study evaluation.

Article 37 establishes the minimum environmental conditions that must be considered: population density; urban and community infrastructure; land use; building development; traffic generation and urban public transport requirements; ventilation and illumination; urban landscape, natural and cultural environment.

Article 38 states further that neighbourhood impact studies do not dispense with the need for other studies or other environmental legislation requirements.

Methodology

Mendes (2004), when undertaking a neighbourhood impact study for a new condominium, proposed an impact classification comprising three levels in terms of: (1) consequence (positive or negative); (2) relationship with the enterprise (direct or indirect); and (3) intensity (high, medium or low).

Based on such a survey, Mendes proposed an impact matrix of factors including: soil, relief, vegetation, buildings, scenery, water supply, wastewater, urban drainage, traffic generation, and urban road capacity. The impacts determined for the construction phase were related to: soil and rock excavation, embankment construction, waste dumping, noise generation, and heavy vehicle traffic.

Moreira (1997) presented an analysis of 26 neighbourhood impact studies performed in São Paulo that considered the impact of: water, wastewater, electrical supply, urban drainage, gas supply, telephone services, urban roads, public transportation, urban scenery, and natural resources. Moreira concluded that a final evaluation of the neighbourhood impact study must demonstrate that the enterprise is compatible with: (1) the proposed urban transportation systems; (2) the urban drainage system; (3) the proposed water, wastewater, and electric supply systems; (4) the planned urban transformation; and (5) conserving the urban environment.

Deficiencies and Problems

The deficiencies of the neighbourhood impact approach can be considered as: (1) legal and (2) execution.

Legal deficiencies include the imprecision of Law 10.257 in terms of how to develop the neighbourhood impact study. This is because of the generic character of this Law 10.257, intended only to direct municipal laws. However, most Brazilian cities established laws that only provided the minimum conditions for a neighbourhood impact study.

Law 10.257 also contains some ambiguous or ill-defined terms, such as *urban and community equipment* and *urban scenery and natural and cultural patrimony*, whose application needs tighter specification. For instance, soil, rock, surface and groundwater are not specifically required.

PROPOSED METHODOLOGY

Principles

One way to reduce problems in neighbourhood impact studies is to better specify the environmental factors. Another way is to define, with the maximum possible accuracy, the area of influence for the enterprise and consequently its neighbourhood.

This study has been based on constructing a matrix of impacts: the *impact evaluation method*. Despite its simplicity, this technique offers a number of advantages: agility and flexibility. The technique was originally proposed by Leopold *et al.* (1971) and is the most used technique for environmental impact evaluation.

The basic structure consists of a representation of the impacts in the columns and phases of work in the rows. The cells contain the user attributes values for each impact in terms of its intensity (Table 1).

Table 1. Basic structure of the impact matrix.

Work Phase	Intervention	Impact	Environmental Component			
Planning	description	description	I+	A+	M-	D+
		description	T+	D-	B+	P+
	description	description	M+	P-	T-	I-
		description	A-	T+	I+	M-
	description	description	P+	I+	B+	D+
		description	A+	M+	T+	P-
		description	D-	T-	A+	I-
	description	description	B-	D+	P+	A-
Construction / Adaptation	description	description	I+	P-	D+	B-
	description	description	P-	A+	I-	T+
	description	description	P-	B+	M+	D-
	description	description	M-	I-	T-	A-
Operation	description	description	D+	A+	P-	M-
	description	description	A-	B-	T-	I-
	description	description	T-	I+	A+	B+
	description	description	M+	P+	B-	D-

Impact Classification

In order to evaluate the matrix, it is necessary to classify it in terms of nature, order, intensity and length. The impacts were considered as being positive (beneficial) or negative (prejudicial). Classification was in terms of class order: direct (an impact with a clear relationship with the enterprise) or indirect (unclear).

For impact intensity, the classes were: high (when the impact provoked complete alteration of the environmental component), low (little alteration), and medium (the alteration compromised the environmental component but did not destroy it).

In terms of length, the impacts were classified as: temporary (when the impact occurs only within a specific time interval of the enterprise being constructed), or permanent.

Environmental Components

Due to the legal deficiencies, the environmental components had to be explicitly specified. Four groups were selected in terms of impact on: the natural environment, city planning, urban infrastructure, and sanitary conditions.

For the natural environment the components considered were: soil, rock, relief, surface water, groundwater, natural landscape, vegetation, soil use and occupation. The components for city planning were: population density, urban density, building, ventilation and illumination, urban landscape, natural and cultural environment.

The urban infrastructure involved components related to services like urban roads, public transport, waste water, urban drainage, electric power, telephonic communications, and public security.

For soils and rocks, the impacts considered included: physical degradation (e.g. erosion), and chemical degradation (pollution and contamination). Surface water considered the effects of: silting, drainage and wastewater spillage.

GEOINDICATORS

One of the most difficult aspects of a neighbourhood impact study relates to the survey. Geoindicators have been found to provide an efficient way of establishing neighbourhood impact in a rapid and reliable manner.

The term geoindicator was used by Berger & Iams (1996) to describe a geological set of information concerning that state of the environment (Table 2).

Geoindicators should be: (1) Scientifically credible; (2) Validated as necessary; (3) Measured at more than one time interval; (4) Related to environmental change; (5) Clear and simple; (6) Relevant; (7) Representative of the phenomenon; (8) Amenable to application of a threshold; (9) Geographical in scope.

Since its definition, such indicators have been used as a tool to describe environmental conditions in a number of environmental settings, such as coastal dynamics (Bush *et al.*, 1999); landslides (Dai *et al.*, 2001); and water resources (Klimas & Gregorauskas, 2002). In Brazil, geoindicators have been used to analyse environmental conditions in coastal areas (Zuquette *et al.*, 2004) and river environments (Santo & Sánchez, 2002).

For this work, geoindicators have been selected which can be used to survey environmental conditions related to: groundwater quality, groundwater level, sediment sequence and composition, slope failure, soil and sediment erosion, soil quality, and surface water quality.

These geoindicators were surveyed from information obtained from public administration and industrial concerns from the São Carlos Science Park.

Table 2. Geoindicators, after Berger (1997).

Geoindicators	Some environmental changes they reflect
Coral chemistry and growth patterns	Temperature of oceanic and coastal surface water, salinity
Desert surface crusts and fissures	Aridity
Dune formation and reactivation	Wind speed and direction, moisture, aridity, sediment availability
Dust storm magnitude, duration and frequency	Dust transport, aridification, land use
Frozen ground activity	Climate, hydrology, downslope movement – especially in the active layer
Glacier fluctuations	Precipitation, insolation, melt runoff
Groundwater quality	Industrial, agricultural and urban pollution, rock and soil weathering, land use, radioactivity, acid precipitation
Groundwater chemistry in the unsaturated zone	Weathering, climate, land use
Groundwater level	Climate, abstraction and recharge
Karst activity	Groundwater chemistry and flow, climate, vegetation cover, fluvial processes
Lake levels and salinity	Climate, land use, streamflow, groundwater flow
Relative sea level	Coastal subsidence and uplift, climate, fluid withdrawal, sedimentation and compaction
Sediment sequence and composition	Climate, land use, erosion and deposition
Seismicity	Natural & human-induced release of earth stresses
Shoreline position	Coastal erosion, sediment transport and deposition, land use, sea levels, climate
Slope failure (landslides)	Slope stability, slow and rapid mass movement, land use
Soil and sediment erosion	Climate, surface runoff, wind, land use
Soil quality	Chemical, biological and physical soil processes, land use
Streamflow	Climate, precipitation, basin discharge, land use
Stream channel morphology	Sediment load, flow rates, climate, land use, surface displacement
Stream sediment storage and load	Sediment transport, flow rates, basin discharge, land use
Subsurface temperature regime	Climate, heat flow, land use, vegetation cover
Surface displacement	Land uplift and subsidence, faulting, fluid extraction
Surface water quality	Climate, land use, water-soil-rock interactions, flow rates
Volcanic unrest	Near-surface movement of magma, magmatic degassing, heat flow
Wetlands extent, structure, and hydrology	Land use, climate, biological productivity, streamflow
Wind erosion	Climate, land use, vegetation cover

RESULTS

The impacts of the São Carlos industrial development in terms of the natural environment are illustrated in Table 3. The next phase was to evaluate their impact using a numerical classification on a scale: direct impact = 3, indirect = 1; high intensity = 3, 2 for medium, and 1 for low; for length the values were 1 for temporary and 3 for permanent. For natural factors, the negative impacts were given the symbol "–" and positive, the symbol "+". The evaluation is presented in Table 4.

Table 3. Identified impacts of the São Carlos High Technology industrial development

Industry Code	Soil	Relief	Rock	Natural landscape	Vegetation	Soil use and occupation	Surface water	Ground-water
1						X	X	
2						X	X	
3						X	X	
4	X		X		X	X	X	
5						X	X	
6						X	X	
7						X	X	
8	X		X		X	X	X	
9	X		X			X		
10						X	X	
11					X	X		
12						X	X	
13						X		
14					X	X		X
15					X	X	X	
16						X	X	
17					X	X	X	
18						X	X	
19						X	X	
20				X	X	X	X	
21						X	X	
22						X	X	
23						X	X	
24					X	X		
25						X	X	
26	X	X	X		X	X	X	
27						X	X	
28						X		
29						X		
30						X	X	
31	X		X			X		
32						X	X	
33						X	X	
34						X	X	
35						X	X	
36					X	X	X	
37					X	X	X	
38					X	X	X	
39						X	X	
40						X	X	
41						X	X	
42						X	X	
43						X		
44	X	X	X		X	X	X	
45						X	X	
46						X	X	
47						X	X	
48						X		
49					X	X		
50						X	X	

Table 4. Neighbourhood Impacts of the São Carlos High Technology industrial development

Industry Code	Soil	Relief	Rock	Natural landscape	Vegetation	Soil use and occupation	Surface water	Ground-water
1						-4	-3	
2						-5	-3	
3						-5	-3	
4	-7		-7		-12	-5	-8	
5						-4	-3	
6						-5	-3	
7						-5	-5	
8	-14		-14		-4	-4	-3	
9	-5		-5			-4		
10						-5	-3	
11					-12	-4		
12						-5	-5	
13						-5		
14					-2	-4		-7
15					-10	-4	-3	
16						-5	-5	
17					-2	-5	-3	
18						-5	-3	
19						-3	-5	
20				-2	-10	-5	-5	
21						-5	-5	
22						-5	-3	
23						-5	-5	
24					-4	-3		
25						-5	-5	
26	-12	-6	-12		-12	-2	-5	
27						-5	-3	
28						-5		
29						-5		
30						-5	-3	
31	-5		-5			-5		
32						-4	-3	
33						-5	-2	
34						-3	-3	
35						-5	-3	
36					-10	-5	-5	
37					-10	-5	-9	
38					-10	-4	-2	
39						-5	-5	
40						-5	-3	
41						-5	-2	
42						-5	-3	
43						-5		
44	-14	-5	-14		-2	-3	-3	
45						-4	-3	
46						-4	-5	
47						-5	-5	
48						-3		
49					-10	-5		
50						-5	-2	

An interesting outcome is that the spatial distribution within the urban area is not uniform. This is due to two main factors: (1) factories constructed more recently having a large size tend to be concentrated in specific areas, e.g. the north and north-west; (2) small factories are concentrated in the central urban area, illustrated in Figures 1 to 3.

Figure 1. Companies concentrated in the *Santa Felícia High Technology District*

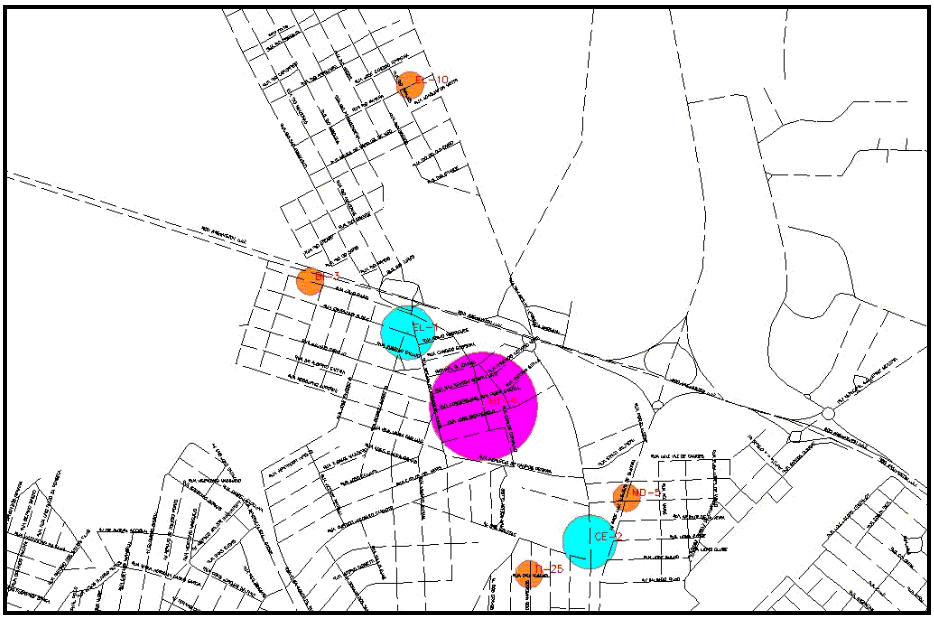

Figure 2. Companies concentrated in the *Industrial District #3*

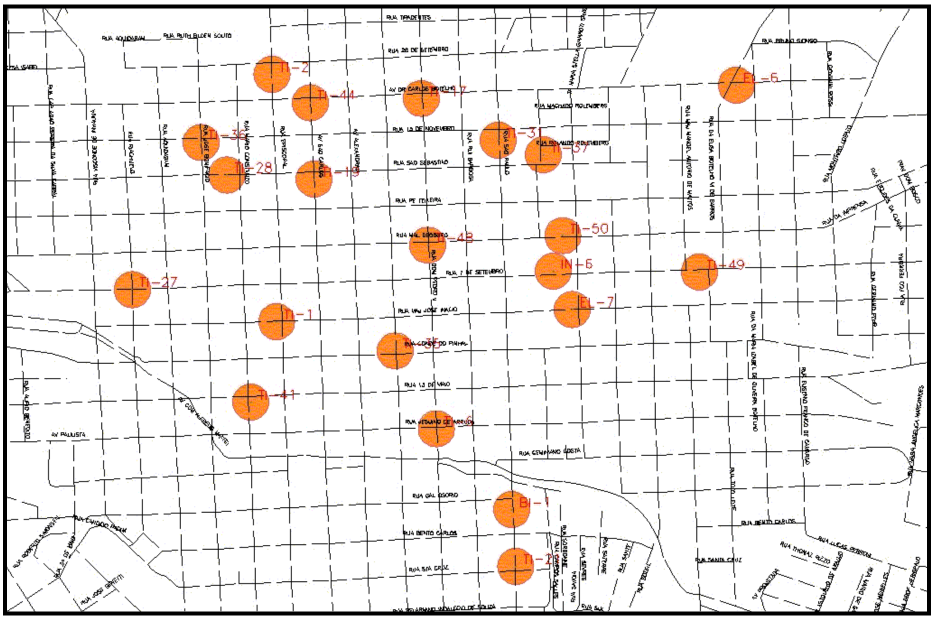

Figure 3. Companies concentrated in the São Carlos urban central area.

Table 4 reveals the sum of the neighbourhood impacts on the natural environment, showing rather limited impact. The less affected components were: soil, rock, natural landscape and groundwater. Otherwise impact occurs without a specific spatial pattern, related to soil use and change in occupation.

Some companies present a more significant impact (e.g. sites 4, 8, 26 and 44 [Figure 3]) due to their major size. These variations are illustrated in Figure 4 using proportional symbols.

Figure 4. Proportional symbols to illustrate the natural environment neighbourhood impact.

CONCLUSIONS

The majority of industrial developments have made only small neighbourhood impacts in terms of the natural environment. Their value shows a close relation with soil use and occupation, and less so with other natural components.

The use of geoindicators, in association with GIS, permits a more efficient system for neighbourhood impact evaluation.

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