5

Geo-environmental Terrain Assessments Based on Remote Sensing Tools: A Review of Applications to Hazard Mapping and Control

Paulo Cesar Fernandes[1] da Silva and John Canning Cripps[2]
[1]*Geological Institute - São Paulo State Secretariat of Environment,*
[2]*Department of Civil and Structural Engineering,*
University of Sheffield,
[1]*Brazil*
[2]*United Kingdom*

1. Introduction

The responses of public authorities to natural or induced geological hazards, such as land instability and flooding, vary according to different factors including frequency of occurrence, severity of damage, magnitude of hazardous processes, awareness, predictability, political willingness and availability of financial and technological resources. The responses will also depend upon whether the hazard is 1) known to be already present thus giving rise to risk situations involving people and/or economic loss; or 2) there is a latent or potential hazard that is not yet present so that development and land uses need to be controlled in order to avoid creating risk situations. In this regard, geo-environmental management can take the form of either planning responses and mid- to long-term public policy based territorial zoning tools, or immediate interventions that may involve a number of approaches including preventative and mitigation works, civil defence actions such as hazard warnings, community preparedness, and implementation of contingency and emergency programmes.

In most of cases, regional- and local-scale terrain assessments and classification accompanied by susceptibility and/or hazard maps delineating potential problem areas will be used as practical instruments in efforts to tackle problems and their consequences. In terms of planning, such assessments usually provide advice about the types of development that would be acceptable in certain areas but should be precluded in others. Standards for new construction and the upgrading of existing buildings may also be implemented through legally enforceable building codes based on the risks associated with the particular terrain assessment or classification.

The response of public authorities also varies depending upon the information available to make decisions. In some areas sufficient geological information and knowledge about the causes of a hazard may be available to enable an area likely to be susceptible to hazardous processes to be predicted with reasonable certainty. In other places a lack of suitable data may result in considerable uncertainty.

In this chapter, a number of case studies are presented to demonstrate the methodological as well as the predictive and preventative aspects of geo-environmental management, with a particular view to regional- and semi-detailed scale, satellite image based terrain classification. If available, information on the geology, geomorphology, covering material characteristics and land uses may be used with remotely sensed data to enhance these terrain classification outputs. In addition, examples provided in this chapter demonstrate the identification and delineation of zones or terrain units in terms of the likelihood and consequences of land instability and flooding hazards in different situations. Further applications of these methods include the ranking of abandoned and/or derelict mined sites and other despoiled areas in support of land reclamation and socio-economic regeneration policies.

The discussion extends into policy formulation, implementation of environmental management strategies and enforcement regulations.

2. Use of remote densing tools for terrain assessments and territorial zoning

Engineering and geo-environmental terrain assessments began to play an important role in the planning process as a consequence of changing demands for larger urban areas and related infra-structure, especially housing, industrial development and the services network. In this regard, the inadequacy of conventional agriculturally-orientated land mapping methods prompted the development of terrain classification systems completely based on the properties and characteristics of the land that provide data useful to engineers and urban planners. Such schemes were then adopted and widely used to provide territorial zoning for general and specific purposes.

The process of dividing a country or region into area parcels or zones, is generally called land or terrain classification. Such a scheme is illustrated in Table 1. The zones should possess a certain homogeneity of characteristics, properties, and in some cases, conditions and expected behaviour in response to human activities. What is meant by homogeneous will depend on the purpose of the exercise, but generally each zone will contain a mixture of environmental elements such as rocks, soils, relief, vegetation, and other features. The feasibility and practicability of delineating land areas with similar attributes have been demonstrated throughout the world over a long period of time (e.g. Bowman, 1911; Bourne, 1931; Christian, 1958; Mabbutt, 1968; amongst others), and encompass a wide range of specialisms such as earth, biological and agricultural sciences; hydrology and water resources management; military activities; urban and rural planning; civil engineering; nature and wildlife conservation; and even archaeology.

According to Cendrero et al. (1979) and Bennett and Doyle (1997), there are two main approaches to geo-environmental terrain assessments and territorial zoning, as follows. 1) The analytical or parametric approach deals with environmental features or components individually. The terrain units usually result from the intersection or cartographic summation of several layers of information [thus expressing the probability limits of findings] and their extent may not corresponding directly with ground features. Examples of the parametric approach for urban planning, hazard mapping and engineering purposes are given by Kiefer (1967), Porcher & Guillope (1979), Alonso Herrero et al. (1990), and Dai et al. (2001). 2) In the synthetic approach, also termed integrated, landscape or physiographic approach, the form and spatial distribution of ground features are analysed in an integrated manner relating recurrent landscape patterns expressed by an interaction of

Terrain unit	***Definition***	***Soil unit***	***Vegetation unit***	***Mapping scale (approx.)***	***Remote sensing platform***
Land zone	Major climatic region	Order	-	< 1:50,000,000	
Land division	Gross continental structure	Suborder	Plant panformation Ecological zone	1:20,000,000 to 1:50,000,000	Meteorological satellites
Land province	Second-order structure or large lithological association	Great group	-	1:20,000,000 to 1:50,000,000	
Land region	Lithological unit or association having undergone comparable geomorphic evolution	Subgroup	Sub-province	1:1,000,000 to 1:5,000,000	Landsat SPOT ERS
Land system *	Recurrent pattern of genetically linked land facets	Family	Ecological region	1: 200,000 to 1:1,000,000	Landsat SPOT, ERS, and small scale aerial photographs
Land catena	Major repetitive component of a land system	Association	Ecological sector	1:80,000 to 1:200,000	
Land facet	Reasonably homogeneous tract of landscape distinct from surrounding areas and containing a practical grouping of land elements	Series	Sub-formation; Ecological station	1:10,000 to 1: 80,000	Medium scale aerial photographs, Landsat, and SPOT in some cases
Land clump	A patterned repetition of two or more land elements too contrasting to be a land facet	Complex	Sub-formation; Ecological station	1:10,000 to 1: 80,000	
Land subfacet	Constituent part of a land facet where the main formative processes give material or form subdivisions	Type	-	Not mapped	Large-scale aerial photographs
Land element	Simplest homogeneous part of the landscape, indivisible in form	Pedon	Ecological station element		

Table 1. Hierarchical classification of terrain, soil and ecological units [after Mitchell, 1991]

environmental components thus allowing the partitioning of the land into units. Since the advent of airborne and orbital sensors, the integrated analysis is based in the first instance, on the interpretation of remotely sensed images and/or aerial photography. In most cases, the content and spatial boundaries of terrain units would directly correspond with ground features. Assumptions that units possessing similar recurrent landscape patterns may be expected to be similar in character are required for valid predictions to be made by extrapolation from known areas. Thus, terrain classification schemes offer rational means of correlating known and unknown areas so that the ground conditions and potential uses of unknown areas can be reasonably predicted (Finlayson, 1984; Bell, 1993). Examples of the applications of the landscape or physiographic approach include ones given by Christian & Stewart (1952, 1968), Vinogradov et al. (1962), Beckett & Webster (1969); Meijerink (1988), and Miliaresis (2001).

Griffiths and Edwards (2001) refer to Land Surface Evaluation as a procedure of providing data relevant to the assessment of the sites of proposed engineering work. The sources of data include remotely sensed data and data acquired by the mapping of geomorphological features. Although originally viewed as a process usually undertaken at the reconnaissance or feasibility stages of projects, the authors point out its utility at the constructional and post-construction stages of certain projects and also that it is commonly applied during the planning of engineering development. They also explain that although more reliance on this methodology for deriving the conceptual or predictive ground model on which engineering design and construction are based, was anticipated in the early 1980s, in fact the use of the methods has been more limited.

Geo-environmental terrain assessments and territorial zoning generally involve three main stages (IG/SMA 2003; Fernandes da Silva et al. 2005b, 2010): 1) delimitation of terrain units; 2) characterisation of units (e.g. in bio-geographical, engineering geological or geotechnical terms); and 3) evaluation and classification of units. The delimitation stage consists of dividing the territory into zones according to a set of pre-determined physical and environmental characteristics and properties. Regions, zones or units are regarded as distinguishable entities depending upon their internal homogeneity or the internal interrelationships of their parts. The characterisation stage consists of attributing appropriate properties and characteristics to terrain components. Such properties and characterisitics are designed to reflect the ground conditions relevant to the particular application. The characterisation of the units can be achieved either directly or indirectly, for instance by means of: (a) ground observations and measurements, including in-situ tests (e.g. boring, sampling, infiltration tests etc); (b) laboratory tests (e.g. grain size, strength, porosity, permeability etc); (c) inferences derived from existing correlations between relevant parameters and other data such as those obtained from previous mapping, remote sensing, geophysical surveys and geochemical records. The final stage (evaluation and classification) consists of evaluating and classifying the terrain units in a manner relevant to the purposes of the particular application (e.g. regional planning, transportation, hazard mapping). This is based on the analysis and interpretation of properties and characteristics of terrain - identified as relevant - and their potential effects in terms of ground behaviour, particularly in response to human activities.

A key issue to be considered is sourcing suitable data on which to base the characterisation, as in many cases derivation by standard mapping techniques may not be feasible. The large size of areas and lack of accessibility, in particular, may pose major technical, operational, and economic constraints. Furthermore, as indicated by Nedovic-Budic (2000), data collection and integration into useful databases are liable to be costly and time-consuming operations. Such problems are particularly prevalent in developing countries in which suitably trained staff, and scarce organizational resources can inhibit public authorities from properly benefiting from geo-environmental terrain assessment outputs in planning and environmental management instruments. In this regard, consideration has been given to increased reliance on remote sensing tools, particularly satellite imagery. The advantages include: (a) the generation of new data in areas where existing data are sparse, discontinuous or non-existent, and (b) the economical coverage of large areas, availability of a variety of spatial resolutions, relatively frequent and periodic updating of images

(Lillesand and Kiefer 2000; Latifovic et al. 2005; Akiwumi and Butler 2008). It has also been proposed that developing countries should ensure that options for using low-cost technology, methods and products that fit their specific needs and capabilities are properly considered (Barton et al. 2002, Câmara and Fonseca 2007). Some examples are provided here to demonstrate the feasibility of a low-cost technique based on the analysis of texture of satellite imagery that can be used for delimitation of terrain units. The delimited units may be further analysed for different purposes such as regional and urban planning, hazard mapping, and land reclamation.

The physiographic compartmentalisation technique (Vedovello 1993, 2000) utilises the spatial information contained in images and the principles of convergence of evidence (see Sabins 1987) in a systematic deductive process of image interpretation. The technique evolved from engineering applications of the synthetic land classification approach (e.g. Grant, 1968, 1974, 1975; TRRL 1978), by incorporating and advancing the logic and procedures of geological-geomorphological photo-interpretation (see Guy 1966, Howard 1967, Soares and Fiori 1976), which were then converted to monoscopic imagery (as elucidated by Beaumont and Beaven 1977; Verstappen 1977; Soares et al. 1981; Beaumont, 1985; and others). Image interpretation is performed by identifying and delineating textural zones on images according to properties that take into account coarseness, roughness, direction and regularity of texture elements (Table 2). The key assumption proposed by Vedovello (1993, 2000) is that zones with relatively homogeneous textural characteristics in satellite images (or air-photos) correspond with specific combinations of geo-environmental components (such as bedrock, topography and landforms, soils and covering materials) which share a common tectonic history and land surface evolution. The particular combinations of geo-environmental components are expected to be associated with specific ground responses to engineering and other land-use actions. The process of image interpretation (whether or not supported by additional information) leads to a cartographic product in which textural zones constitute comprehensive terrain units delimited by fixed spatial boundaries. The latter correspond with ground features. The units are referred to as physiographic compartments or basic compartmentalisation units (BCUs), which are the smallest units for analysis of geo-environmental components at the chosen cartographic scale (Vedovello and Mattos 1998). The spatial resolution of the satellite image or air-photos being used for the analysis and interpretation is assumed to govern the correlation between image texture and terrain characteristics. This correlation is expressed at different scales and levels of compartmentalisation. Figure 1 presents an example of the identification of basic compartmentalisation units (BCUs) based on textural differences on Landsat TM5 images. In this case the features on images are expressions of differences in the distribution and spatial organisation of textural elements related to drainage network and relief. The example shows the contrast between drainage networks of areas consisting of crystalline rocks with those formed on areas of sedimentary rocks, and the resulting BCUs.

3. Terrain susceptibility maps: applications to regional and urban planning

Terrain susceptibility maps are designed to depict ground characteristics (e.g. slope steepness, landforms) and observed and potential geodynamic phenomena, such as erosion, instability and flooding, which may entail hazard and potential damage. These maps are useful for a number of applications including development and land use planning, environmental protection, watershed management as well as in initial stages of hazard mapping applications.

Textural entities and properties	Description
Image texture element	The smallest continuous and uniform surface liable to be distinguishable in terms of shape and dimensions, and likely to be repetitive throughout an image. Usual types of image texture elements taken for analysis include: segments of drainage or relief (e.g. crestlines, slope breaks) and grey tones.
Texture density	The quantity of textural elements occurring within an area on image. Texture density is defined as the inverse of the mean distance between texture elements. Although it reflects a quantitative property, textural density is frequently described in qualitative and relative terms such as high, moderate, low etc. Size of texture elements combined with texture density determine features such as coarseness and roughness.
Textural arrangement	The form (ordered or not) by which textural elements occur and are spatially distributed on an image. Texture elements of similar characteristics may be contiguous thus defining alignments or linear features on the image. The spatial distribution may be repetitive and it is usually expressed by 'patterns' that tend to be recurrent (regularity). For example, forms defined by texture elements due to drainage expressed in rectangular, dendritic, or radial patterns.
Structuring (Degree of spatial organisation)	The greater or lesser organisation underlying the spatial distribution of textural elements and defined by repetition of texture elements within a certain rule of placement. Such organisation is usually expressed in terms of regular or systematic spatial relations, such as length, angularity, asymmetry, and especially prevailing orientations (tropy or directionality). Tropy reflects the anisotropic (existence of one, two, or three preferred directions), or the isotropic (multi-directional or no predominant direction) character of textural features. Asymmetry refers to length and angularity of linear features (rows of contiguous texture elements) in relation to a main feature identified on image. The degree of organisation can also be expressed by qualitative terms such as high, moderate, low, or yet as well- or poorly-defined.
Structuring order	Complexity in the organisation of textural elements, mainly reflecting superposition of image structuring. For example, a regional directional trend of textural elements that can be extremely pervasive, distinctive and superimposed on other orientations also observed on imagery. Another example is drainage networks that display different orders with respect to main stream lines and tributaries (1st, 2nd, 3rd orders)

Table 2. Description of elements and properties used for recognition and delineation of distinctive textural zones on satellite imagery [after Vedovello 1993, 2000].

Early multipurpose and comprehensive terrain susceptibility maps include examples by Dearman & Matula, (1977), Matula (1979), and Matula & Letko (1980). These authors described the application of engineering geology zoning methods to the urban planning process in the former Republic of Czechoslovakia. The studies in this and other countries focused on engineering geology problems related to geomorphology and geodynamic processes, seismicity, hydrogeology, and foundation conditions.

Culshaw and Price (2011) point out that in the UK, a major initiative on urban geology began in the mid-1970s with obtaining geological information relevant to aggregates and other industrial minerals together with investigations relating to the planning of the proposed 3rd London Airport. In the latter case, a very wide range of map types was produced, including one that could be viewed in 3D, using green and red anaglyph spectacles. Of particular interest was the summary ''Engineering Planning Map which showed areas that were generally suitable for different types of construction and, also, detailed suggested site investigation procedures (Culshaw and Northmore 2002).

As Griffiths and Hearn (2001) explain, subsequently about 50 experimental 'environmental geological mapping, 'thematic'geological mapping' and 'applied geological mapping' projects were carried out between 1980 and 1996. Culshaw and Price (2011) explain that this was to investigate the best means of collecting, collating, interpreting and presenting geological data that would be of direct applicability in land-use planning (Brook and Marker 1987). Maps of a variety of geological and terrain types, including industrially despoiled and potentially unstable areas, with mapping at scales between 1:2500 and 1:25000 were produced. The derivation and potential applications of these sets of maps and reports are described by Culshaw et al. (1990) who explain that they include basic data maps, derived maps and environmental potential maps. Typically such thematic map reports comprise a series of maps showing the bedrock and superficial geology, thickness of superficial deposits, groundwater conditions and areas of mining, fill, compressible, or other forms of potentially unstable ground. Maps showing factual information include the positions of boreholes or the positions of known mine workings. Derived maps include areas in which geological and / or environmental information has been deduced, and therefore is subject to some uncertainty. The thematic sets include planning advice maps showing the constraints on, and potential for, development and mineral extraction. Culshaw et al. (1990) also explained that these thematic maps were intended to assist with the formulation of both local (town or city), regional (metropolis or county) structure plans and policies, provide a context for the consideration of development proposals and facilitate access to relevant geological data by engineers and geologists. It was also recognised that these is a need for national (or state) policies and planning to be properly informed about geological conditions, not least to provide a sound basis for planning legislation and the issuing of advice and circulars. Examples of such advice include planning guidance notes concerning the granting of planning permission for development on potentially unstable land which were published (DOE, 1990, 1995) by the UK government. A further series of reports which were intended to assist planners and promote the consideration of geological information in land-use planning decision making were compiled between 1994 and 1998 by consultants on behalf of the UK government. Griffiths (2001) provides details of a selection of land evaluation techniques and relevant case studies. These covered the following themes:

- Environmental Geology in Land Use Planning: Advice for planners and developers (Thompson et al., 1998a)
- Environmental Geology in Land Use Planning: A guide to good practice (Thompson et al., 1998b)
- Environmental Geology in Land Use Planning: Emerging issues (Thompson et al., 1998c)
- Environmental Geology in Land Use Planning: Guide to the sources of earth science information for planning and development (Ellsion and Smith, 1998)

For an extensive review of world-wide examples of geological data outputs intended to assist with urban geology interpretation, land-use planning and utilisation and geological hazard avoidance, reference should be made to Culshaw and Price (2001).

Three examples of terrain susceptibility mapping are briefly described and presented in this Section. The physiographic compartmentalisation technique for regional terrain evaluation was explored in these cases, and then terrain units were further characterised in geo-environmental terms.

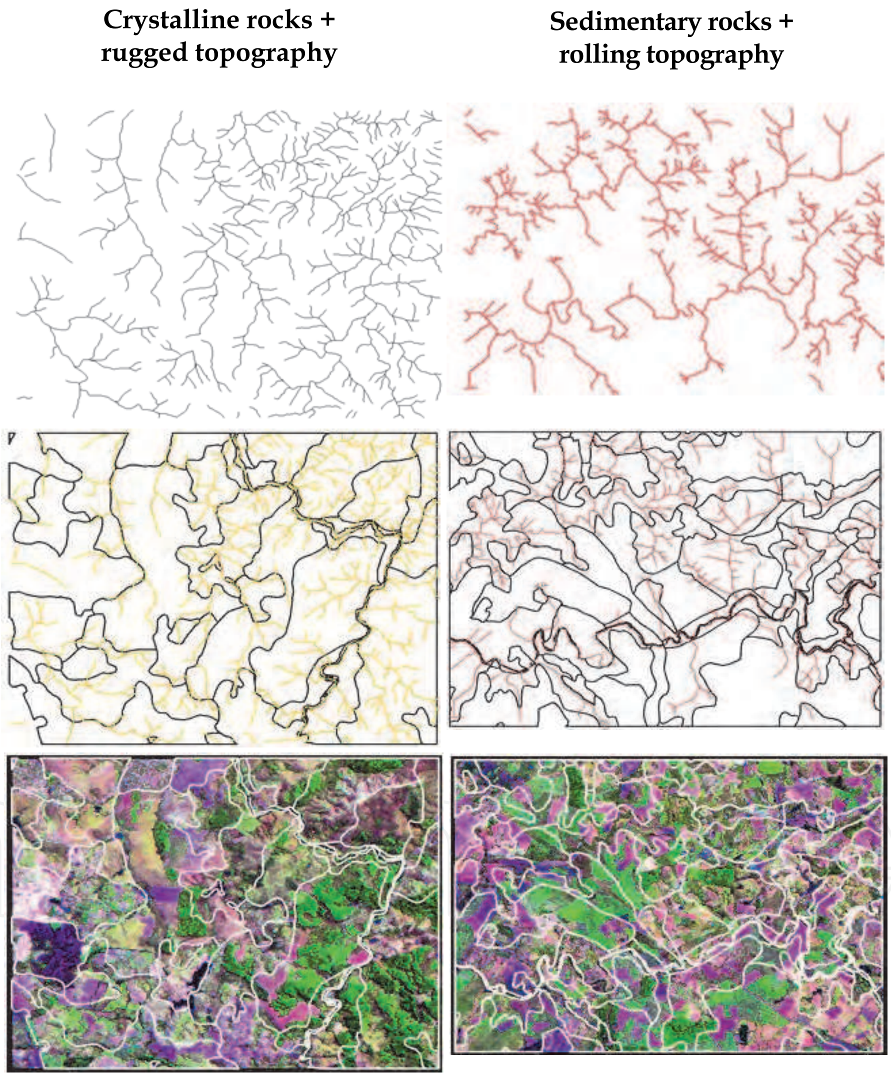


Fig. 1. Identification of basic compartmentalisation units (BCUs) based on textural differences on image. The image for crystalline rocks with rugged topography contrasts with sedimentary rocks with rolling topography. Top: Drainage network. Mid Row: Drainage network and delineated BCUs. Bottom: Composite Landsat TM5 image and delineated BCUs [after Fernandes da Silva et al. 2005b, 2010]

3.1 Multipurpose planning

The first example concerns the production of a geohazard prevention map for the City of São Sebastião (IG/SMA 1996), where urban and industrial expansion in the mountainous coastal zone of São Paulo State, Southeast Brazil (Figure 2) led to conflicts in land use as well as to high risks to life and property. Particular land use conflicts arose from the combinations of landscape and economic characteristics of the region, in which a large nature and wildlife park co-exists with popular tourist and leisure encroached bays and beaches, a busy harbour with major oil storage facilities and associated pipelines that cross the area. Physiographic compartmentalisation was utilised to provide a regional terrain classification of the area, and then interpretations were applied in two ways: (i) to provide a territorial zoning based on terrain susceptibility in order to enable mid- to long-term land use planning; and (ii) to identify areas for semi-detailed hazard mapping and risk assessment (Fernandes da Silva et al. 1997a, Vedovello et al., 1997; Cripps et al., 2002). Figure 2 presents the main stages of the study undertaken in response to regional and urban planning needs of local authorities.

In the Land Susceptibility Map, the units were qualitatively ranked in terms of ground evidence and estimated susceptibility to geodynamic processes including gravitational mass movements, erosion, and flooding.

Criteria for terrain unit classification in relation to erosion and mass movements (landslides, creep, slab failure, rock fall, block tilt and glide, mud and debris flow) were the following: a) soil weathering profile (thickness, textural and mineral constituency); b) hillslope profile; c) slope steepness; and d) bedrock structures (fracturing and discontinuities in general). Criteria in relation to flooding included: a) type of sediments; b) slope steepness; and c) hydrography (density and morphology of water courses). The resulting classes of terrain susceptibility can be summarised as follows:

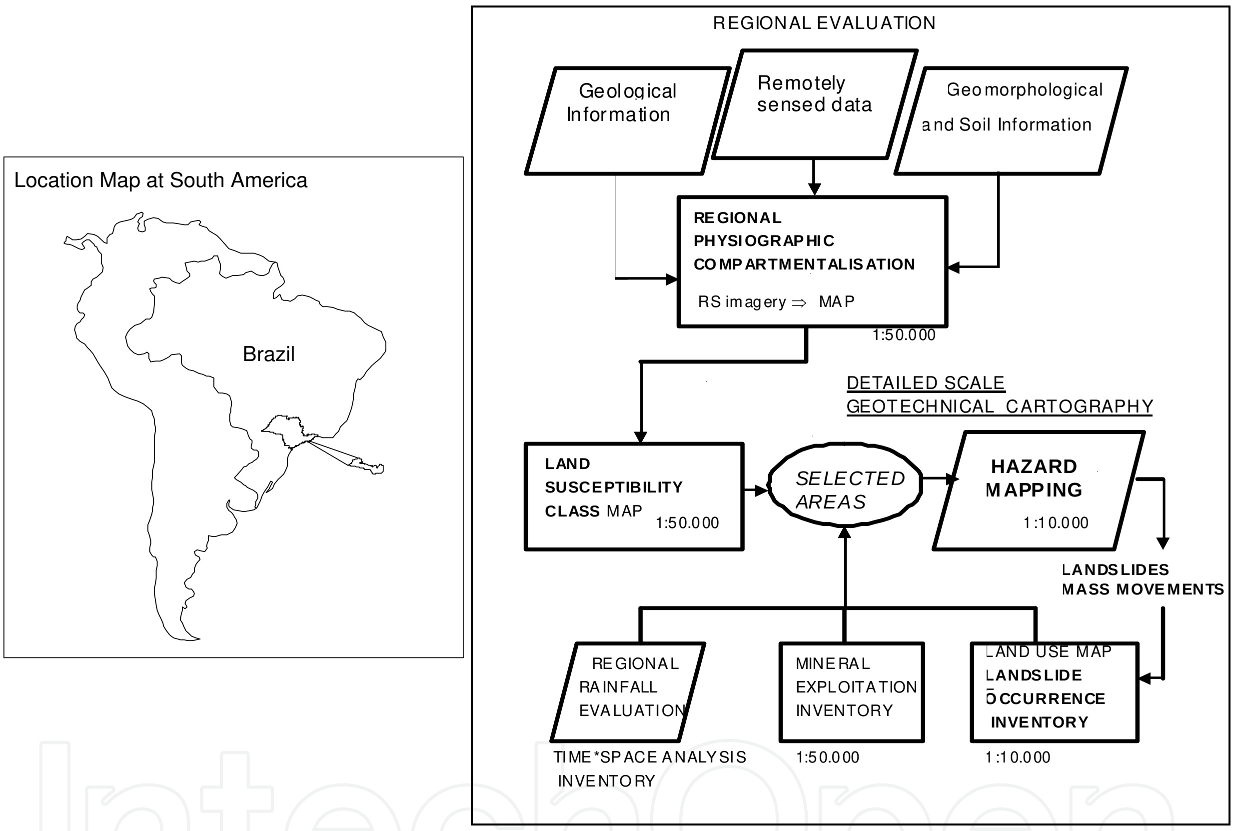
Low susceptibility: Areas where mass movements are unlikely. Low restrictions to excavations and man-made cuttings. Some units may not be suitable for deep foundations or other engineering works due to possible high soil compressibility and presence of geological structures. In flat areas, such as coastal plains, flooding and river erosion are unlikely.

Moderate susceptibility: Areas of moderate to high steep slope (10 to 30%) with little evidence of land instability (small-scale erosional processes may be present) but with potential for occurrence of mass movements. In lowland areas, reported flooding events were associated with the main drainage stream in relevant zones. Terrain units would possess moderate restrictions for land-use with minor engineering solutions and protection measures needed to reduce or avoid potential risks.

High susceptibility: Areas of moderate (10 to 20%) and high steep slope (20 to 30%) situated in escarpment and footslope sectors, respectively, with evidence of one or more active land instability phenomena (e.g. erosion + rock falls + landslide) of moderate magnitude. Unfavourable zones for construction work wherein engineering projects would require accurate studies of structural stability, and consequently higher costs. In lowland sectors, recurrent flooding events were reported at intervals of 5 to 10 yrs, associated with main drainage streams and tributaries. Most zones then in use required immediate remedial action including major engineering solutions and protection measures.

Very high susceptibility: Areas of steeper slopes (> 30%) situated in the escarpment and footslope sectors that mainly comprised colluvium and talus deposits. There was evidence of one or more land instability phenomena of significant magnitude requiring full restriction on construction work. In lowland sectors, widespread and frequent flooding events at intervals of less than 5 years were reported and most land-used needed to be avoided in these zones.

Units or areas identified as having a moderate to high susceptibility to geodynamic phenomena, and potential conflicts in land use, were selected for detailed engineering geological mapping in a subsequent stage of the study. The outcomes of the further stage of hazard mapping are described and discussed in Section 4.



A) B)

Fig. 2. A) Location map for the City of São Sebastião, north shore of São Paulo State, Southeast Brazil. B) Schematic flow diagram for the derivation of the geohazard prevention chart and structural plan (after IG/SMA, 1996).

3.2 Watershed planning and waste disposal

The physiographic compartmentalisation technique was also applied in combination with GIS tools in support of watershed planning in the Metropolitan District of Campinas, central-eastern São Paulo State (Figure 3). This regional screening study was performed at 1:50,000 scale to indicate fragilities, restrictions and potentialities of the area for siting waste disposal facilities (IG/SMA, 1999). A set of common characteristics and properties (also referred to as attributes) facilitated the assessment of each BCU (or terrain unit) in terms of susceptibility to the occurrence of geodynamic phenomena (soil erosion and land instability) and the potential for soil and groundwater contamination.

As described by Brollo et al. (2000), the terrain units were mostly derived on the basis of qualitative and semi-quantitative inferences from satellite and air-photo images in conjunction with existing information (maps and well logs – digital and papers records) and field checks. The set of attributes included: (1) bedrock lithology; (2) density of lineaments (surrogate expression of underlying fractures and terrain discontinuities); (3) angular relation between rock structures and hillslope; (4) geometry and shape of hillslope (plan view and profile); (5) soil and covering material: type, thickness, profile; (6) water table depth; and (7) estimated permeability. These attributes were cross-referenced with other specific factors, including hydrogeological (groundwater production, number of wells per unit area), climatic (rainfall, prevailing winds), and socio-political data (land use, environmental restrictions). These data were considered to be significant in terms of the selection of potential sites for waste disposal.

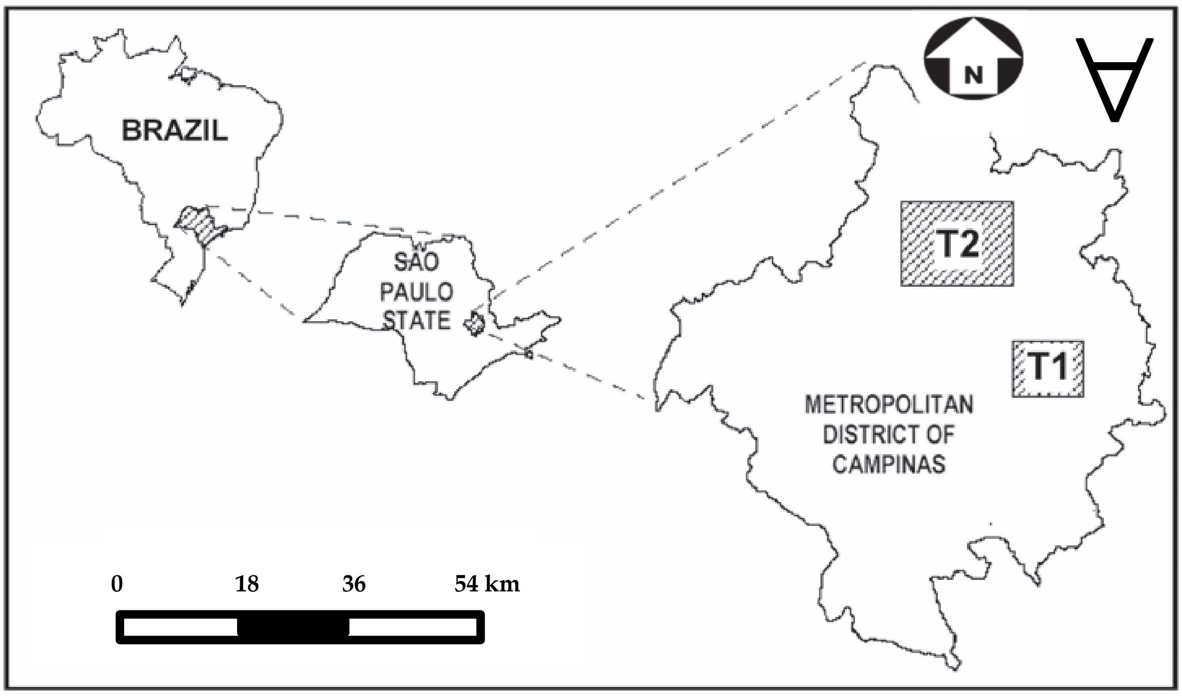
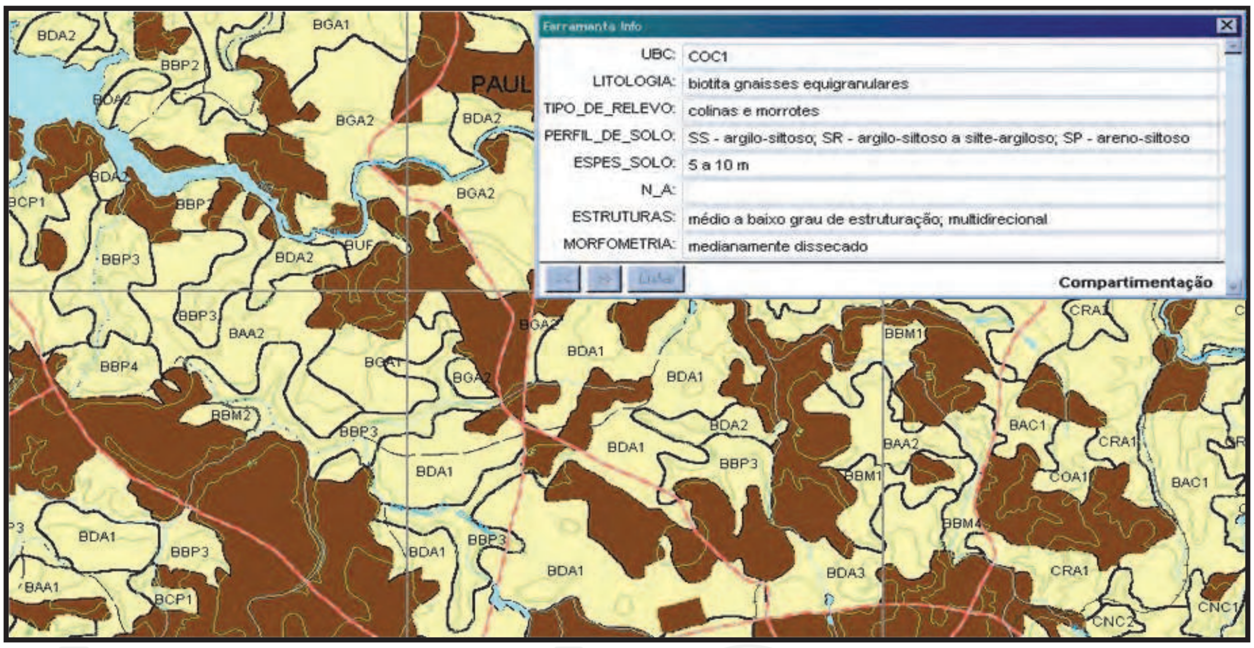


Fig. 3. Location map of the Metropolitan District of Campinas (MDC), central-eastern São Paulo State, Southeast Brazil (see Section 3.2). Detail map depicts Test Areas T1 and T2 within the MDC (see Section 3.3). Scale bar applies to detail map.

Figure 4 displays the study area in detail together with BCUs, and an example of a pop-up window (text box) containing key attribute information, as follows: 1st row - BCU code (COC1), 2nd - bedrock lithology, 3rd - relief (landforms), 4th – textural soil profile constituency, 5th - soil thickness, 6th - water table depth (not show in the example), 7th - bedrock structures in terms of density of fracturing and directionality), 8th - morphometry (degree of dissection of terrain). The BCU coding scheme expresses three levels of compartmentalisation, as follows: 1st letter – major physiographic or landscape domain, 2nd– predominant bedrock lithology, 3rd - predominant landforms, 4th– differential characteristics of the unit such as estimated soil profile and underlying structures. Using the example given in Figure 4, COC1 means: C = crystalline rock basement, O = equigranular gneiss, C = undulating and rolling hills, 1 = estimated soil profile (3 textural horizons and thickness of 5 to 10 m), underlying structures (low to moderate degree of fracturing, multi-directional). In terms of general interpretations for the intended purposes of the study, certain ground characteristics, such as broad valleys filled with alluvial sediments potentially indicate the presence water table level at less than 5 m below ground surface. Flood plains or concave hillside slopes that may indicate convergent surface water flows leading to potentially high susceptibility to erosion, were considered as restrictive factors for the siting of waste disposal facilities (Vedovello et al. 1998).



UBC: COC1
LITOLOGIA: biotita gnaisses equigranulares
TIPO_DE_RELEVO: colinas e morrotes
PERFIL_DE_SOLO: SS - argilo-siltoso; SR - argilo-siltoso a silte-argiloso; SP - areno-siltoso
ESPES_SOLO: 5 a 10 m
N_A:
ESTRUTURAS: médio a baixo grau de estruturação; multidirecional
MORFOMETRIA: medianamente dissecado

Fig. 4. Basic compartmentalisation units (BCUs) and pop-up window showing key attribute information relevant to BCUs. See text for details. [Not to scale] [after IG/SMA, 1999]

3.3 Regional development planning

The third example is a territorial zoning exercise, in which terrain units delimited through physiographic compartmentalisation were further assessed in terms of susceptibility to land instability processes and groundwater vulnerability (Fernandes da Silva et al. 2005b). The study was conducted in two test areas situated in the Metropolitan District of Campinas (Figure 3) in order to assist State of São Paulo authorities in the formulation of regional development policies. It incorporated procedures for inferring the presence and characteristics of underlying geological structures, such as fractures and other discontinuities, then evaluating potential implications to ground stability and the flow of groundwater.

Details of image interpretation procedures for the delimitation of BCUs are described by Fernandes da Silva et al. (2010). The main image properties and image feature characteristics considered were as follows: (a) density of texture elements related to drainage and relief lines; (b) spatial arrangement of drainage and relief lines in terms of form and degree of organisation (direction, regularity and pattern); (c) length of lines and their angular relationships, (d) linearity of mainstream channel and asymmetry of tributaries, (e) density of interfluves, (f) hillside length, and (g) slope forms. These factors were mostly derived by visual interpretation of images, but external ancillary data were also used to assist with the determination of relief-related characteristics, such as slope forms and interfluve dimensions. The example given in Figure 1 shows sub-set images (Landsat TM5) and the basic compartmentalisation units (BCUs) delineated for Test Areas T1 and T2.

Based on the principle that image texture correlates with properties and characteristics of the imaged target, deductions can be made about geotechnical-engineering aspects of the terrain (Beaumont and Beaven 1977, Beaumont 1985). The following attributes were firstly considered in the geo-environmental characterisation of BCUs: (a) bedrock lithology and respective weathered materials, (b) tectonic discontinuities (generically referred to as fracturing), (c) soil profile (thickness, texture and mineralogy), (d) slope steepness (as an expression of local topography), and (e) water table depth (estimated). Terrain attributes such as degree of fracturing, bedrock lithology and presence and type of weathered materials were also investigated as indicators of ground properties. For instance, the mineralogy, grain size and fabric of the bedrock and related weathered materials would control properties such as shear strength, pore water suction, infiltration capacity and natural attenuation of contaminants (Vrba and Civita 1994, Hudec 1998, Hill and Rosenbaum 1998, Thornton et al. 2001, Fernandes 2003). Geological structures, such as faults and joints within the rock mass, as well as relict structures in saprolitic soils, are also liable to exert significant influences on shear strength and hydraulic properties of geomaterials (Aydin 2002, Pine and Harrison 2003). In this particular case study, analysis of lineaments extracted from satellite images combined with tectonic modelling underpinned inferences about major and small-scale faults and joints. The approach followed studies by Fernandes and Rudolph (2001) and Fernandes da Silva et al. (2005b) who asserted that empirical models of tectonic history, based on outcrop scale palaeostress regime determinations, can be integrated with lineament analysis to identify areas: i) of greater density and interconnectivity of fractures; and ii) greater probability of open fractures; also to iii) deduce angular relationships between rock structures (strike and dip) and between these and hill slope directions. These procedures facilitated 3-dimensional interpretations and up-scaling from regional up to semi-detailed assessments which were particularly useful for assessments of local ground stability and groundwater flow.

The BCUs were then classified into four classes (very high, high, moderate, and low) in terms of susceptibility to land instability and groundwater vulnerability according to qualitative and semi-quantitative rules devised from a mixture of empirical knowledge and statistical approaches. A spreadsheet-based approach that used nominal, interval and numerical average values assigned in attribute tables was used for this. A two-step procedure was adopted to produce the required estimates where, at stage one, selected attributes were analysed and grouped into three score categories (A - high, M - moderate, B - low B) according to their potential influence on groundwater vulnerability and land instability processes. In the second step, all attributes were considered to have the same relative influence and the final classification for each BCU was the sum of the scores A, B, M. The possible combinations of these are illustrated in Table 3. Figure 5 shows overall terrain classifications for susceptibility to land instability.

Combinations of scores	Classification
AAAA	Very high
AAAM, AAAB, AAMM	High
AAMB, AABB, AMMM, AMMB, MMMM	Medium
AMBB, ABBB, MMMB, MMBB, MBBB, BBBB	Low

Table 3. Possible combinations of scores "A" (high), "M" (moderate), and "B" (low) respective to the four attributes (bedrock lithology and weathered materials, fracturing, soil type, and slope steepness) used for classification of units (BCUs) in terms of susceptibility to land instability and groundwater vulnerability.

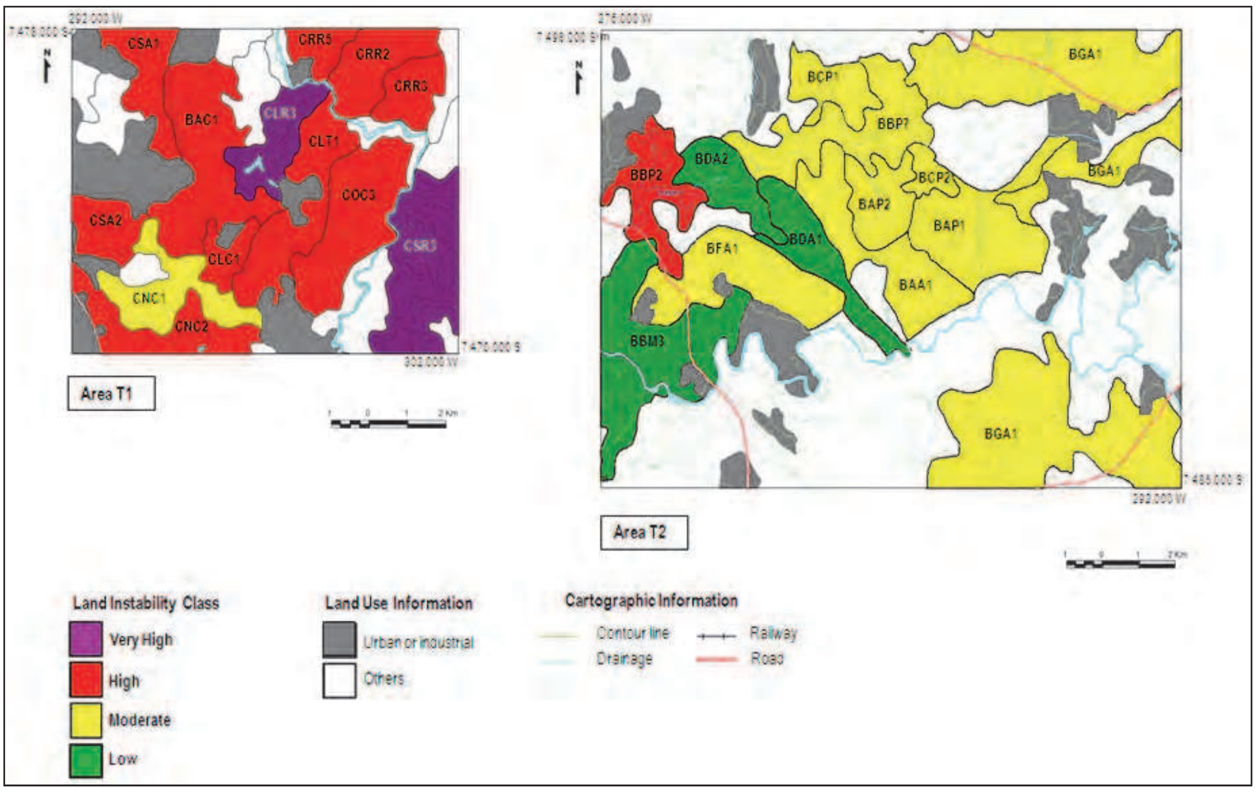


Fig. 5. Maps of susceptibility to land instability processes. Test Areas T1 and T2. UTM projection and coordinates [After Fernandes da Silva et al., 2010].

4. Hazard mapping: Land instability and flooding

In order to prevent damage to structures and facilities, disruption to production, injury and loss of life, public authorities have a responsibility to assess hazard mitigation and controls that may require remedial engineering work, or emergency and contingency actions. In order to accommodate these different demands, information about the nature of the hazard, and the consequences and likelihood of occurrence, are needed. Hazard maps aim to reduce adverse environmental impacts, prevent disasters, as well as to reconcile conflicting influences on land use. The examples given in this Section demonstrate the identification and zonation in terms of the likelihood and consequences of land instability and flooding hazards. There are several reasons for undertaking such work, for instance to provide public authorities with data on which to base structural plans and building codes as well as civil defence and emergency response programmes.

4.1 Application to local structural plans

As indicated in Section 3.1, the BCUs (terrain units) classified as having a moderate to high susceptibility to geodynamic processes (mass movements and flood) were selected for further detailed engineering geological mapping. This was to provide data and supporting information to the structure plan of the City of São Sebastião. The attributes of the selected units were cross-referenced with other data sets, such as regional rainfall distribution, land-use inventory, and mineral exploitation records to estimate the magnitude and frequency of hazards and adverse impacts. Risk assessment was based on the estimated probability of failure occurrence and the potential damage thus caused (security of life, destruction of property, disruption of production). Both the triggering and the predisposing factors were investigated, and, so far as was possible, identified. It is worth noting the great need to consider socio-economic factors in hazard mapping and risk analysis. For instance, areas of consolidated housing and building according to construction patterns and reasonable economic standards were distinguished from areas of unconsolidated/expanding urban occupation. Temporal analysis of imagery and aerial photos, such as densities of vegetation and exposed soil in non-built-up areas, were utilised to supplement the land use inventory. The mineral exploration inventory included the locations of active and abandoned mineral exploitation sites (quarries and open pit mining for aggregates) and certain geotechnical conditions. Besides slope steepness and inappropriate occupancy and land use, the presence of major and minor geological structures was considered to be one of the main predisposing factors to land instability in the region studied.

Figure 6 depicts a detail of the hazard map for the City of São Sebastião. Zones of land instability were delimited and identified by code letters that correspond with geodynamic processes as follows: A - landslides, B - creep, C - block tilt/glide, and D - slab failure/rock fall. Within these zones, landsliding and other mass movement hazards were further differentiated according to structural geological predisposing factors as follows: r – occurrence of major tectonic features such as regional faults or brittle-ductile shear zones; f – coincidence of spatial orientations between rock foliation, hillslope, and man-made cuttings; t – high density of fracturing (particularly jointing) in combination with coincidence of spatial orientations between fracture and foliation planes, hillslope, and man-made cuttings (Moura-Fujimoto et al., 1996; Fernandes da Silva et al. 1997b).

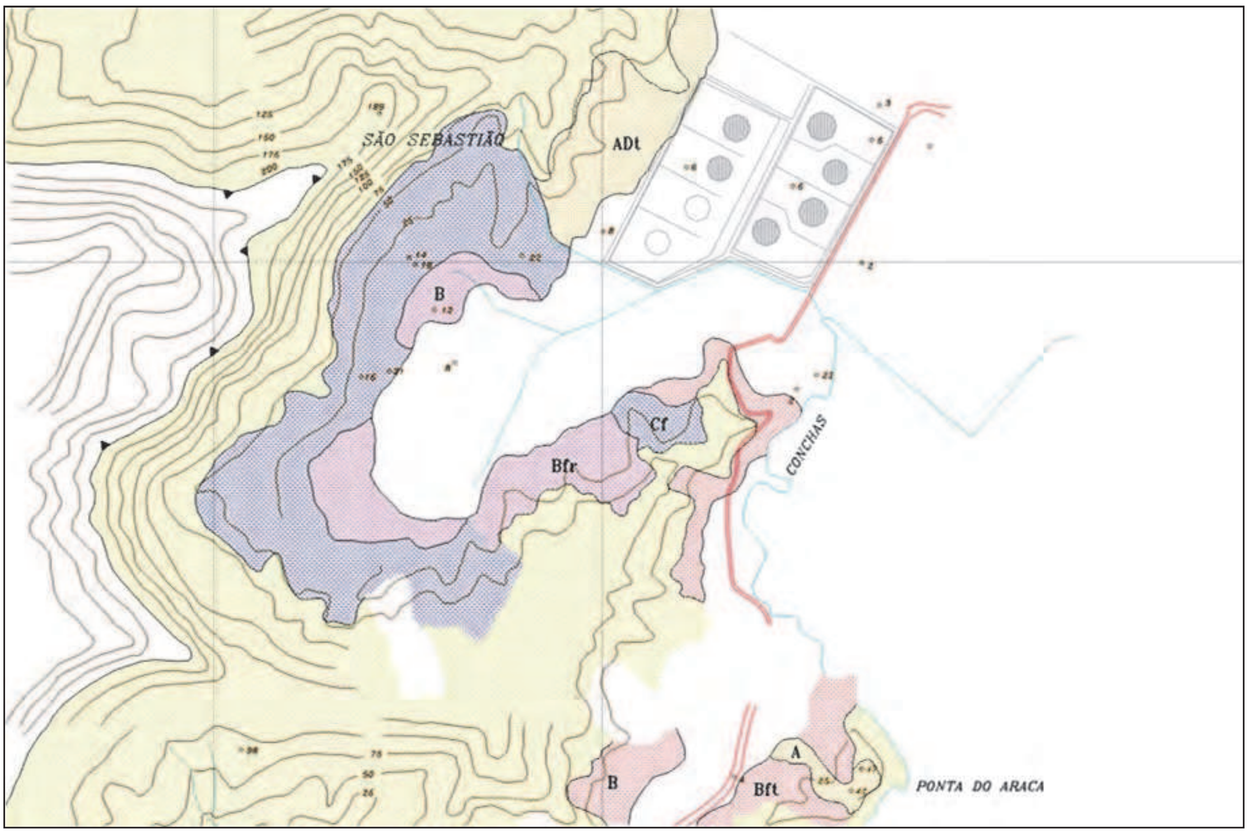


Fig. 6. Example of hazard map from the City of São Sebastião, north shore of São Paulo State, Southeast Brazil. Key for unit classification: Light red = very high susceptibility; Blue = high susceptibility; Light orange = moderate susceptibility; Yellow = low susceptibility. See Section 4.1 for code letters on geodynamic processes and predisposing factors. [after Fernandes da Silva et al. 1997b] (not to scale).

4.2 Application to civil defence and emergency response programmes

Methods of hazard mapping can be grouped into three main approaches: empirical, probabilistic, and deterministic (Savage et al. 2004, as cited in Tominaga, 2009b). Empirical approaches are based on terrain characteristics and previous occurrence of geodynamic phenomena in order to estimate both the potential for, and the spatial and temporal distribution of, future phenomena and their effects. Probabilistic approaches employ statistical methods to reduce subjectivity of interpretations. However, the outcomes depend very much on measured patterns defined through site tests and observations, but it is not always feasible to perform this acquisition of data in developing regions and countries. Deterministic approaches focus on mathematical modelling that aims quantitatively to describe certain parameters and rules thought to control physical processes such as slope stability and surface water flow. Their application tends to be restricted to small areas and detailed studies.

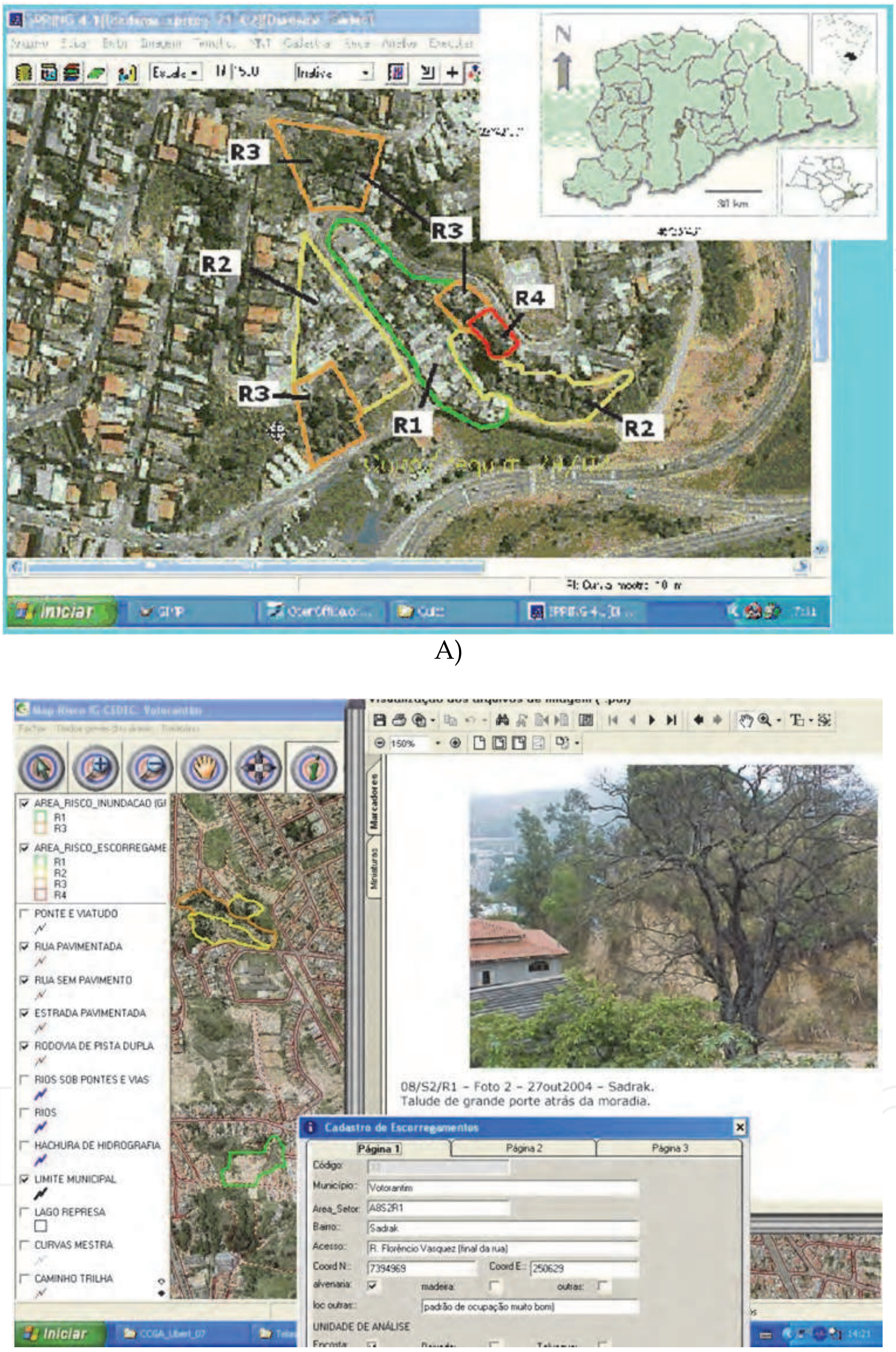
In the State of Sao Paulo (Southeast Brazil), high rates of population influx and poorly planned land occupation have led to concentration of dwellings in unsuitable areas, thus leading to increasing exposure of the community to risk and impact of hazard events. In addition, over the last 20 years, landsliding and flooding events have been affecting an increasingly large geographical area, so bringing about damage to people and properties (Tominaga et al. 2009a). To deal with this situation, Civil Defence actions including preventive, mitigation, contingency (preparedness), and emergency response programmes have been implemented. The assessment of the potential for the occurrence of landslides, floods and other geodynamic processes, besides the identification and management of associated risks in urban areas has played a key role in Civil Defence programmes. To date, systematic hazard mapping has covered 61 cities in the State of São Paulo, and nine other cities are currently being mapped (Pressinotti et al., 2009).

Examples that mix empirical and probabilistic approaches are briefly presented in this Section. The concepts of hazard mapping and risk analysis adopted for these studies followed definitions provided in Varnes (1984) and UN-ISDR (2004), who described risk as an interaction between natural or human induced hazards and vulnerable conditions. According to Tominaga (2009b), a semi-quantitative assessment of risk, R, can be derived from the product $R = [H \times (V \times D)]$, where: H is the estimated hazard or likelihood of occurrence of a geodynamic and potentially hazardous phenomenon; V is the vulnerability determined by a number of physical, environmental, and socio-economic factors that expose a community and/or facilities to adverse impacts; and D is the potential damage that includes people, properties, and economic activities to be affected. The resulting risk, R, attempts to rate the damage to structures and facilities, injury and loss of lives, and disruption to production.

The first example relates to hazard mapping and risk zoning applied to housing urban areas in the City of Diadema (Marchiori-Faria et al. 2006), a densely populated region (around 12,000 inhab. per km^2) of only 31.8 km^2, situated within the Metropolitan Region of the State Capital – São Paulo (Figure 7). The approach combined the use of high-resolution satellite imagery (Ikonos sensor) and ortho-rectified aerial photographs with ground checks. The aim was to provide civil defence authorities and decision-makers with information about land occupation and ground conditions as well as technical advice on the potential magnitude of instability and flooding, severity of damage, likelihood of hazard, and possible mitigating and remedial measures. Driving factors included the need to produce outcomes in an updateable and reliable manner, and in suitable formats to be conveyed to non-specialists. The outcomes needed to meet preventive and contingency requirements, including terrain accessibility, linear infrastructure conditions (roads and railways in particular), as well as estimations of the number of people who would need to be removed from risk areas and logistics for these actions. Risk zones were firstly identified through field work guided by local authorities. Site observations concentrated on relevant terrain characteristics and ground conditions that included: slope steepness and hillslope geometry, type of slope (natural, cut or fill), soil weathering profile, groundwater and surface water conditions, and land instability features (e.g. erosion rills, landslide scars, river undercutting). In addition, information about periodicity, magnitude, and effects of previous landsliding and flooding events as well as perceptions of potential and future problems were gathered through interviewing of residents. Satellite images were further used to assist with the identification of buildings and houses liable to be affected and the delineation of risk zone boundaries. Risk assessment was based on a qualitative ranking scheme with four levels of risk: R1 (low); R2 (moderate); R3 (high); R4 (very-high). Low risk (R1) zones, for example, comprised only predisposing factors to instability (e.g. informal housing and cuttings in steep slope areas) or to flooding (e.g. informal housing in lowland areas and close to watercourses but no reported flood within the last 5 years). Very-high risk (R4) zones were characterized by significant evidence of land instability (e.g. presence of cracks in soil and walls, subsidence steps, leaning of trees and electricity poles, erosion rills and ravines, landslide scars) or flooding hazards (e.g. flooding height marks on walls, riverbank erosion, proximity of dwellings to river channel, severe floods reported within the last 5 years).

The outcomes, including basic and derived data and interpretations, were integrated and then presented on a geo-referenced computational system designed to respond the needs of data displaying and information management of the State of São Paulo Civil Defence authorities (CEDEC). As described by Pressinotti et al. (2007), such system and database, called Map-Risk, includes cartographic data, interpretative maps (risk zoning), imagery, and layers of cadastral information (e.g. urban street network). The system also enabled generation and manipulation of outputs in a varied set of text (reports), tabular (tables), and graphic information including photographic inventories for risk zones. The system was fully conceived and implemented at low cost, utilizing commercial software available that were customized in this visualisation system through target-script programming designed to achieve user functionalities (e.g. ESRI/MapObjects, Delphi, Visual Basic, OCX MapObjects). Examples of delineated risk zones for the City of Diadema and a display of the Map-Risk functionalities are presented in Figure 7.

The second example refers to a flooding hazard mapping performed at regional and local scales in the Paraiba do Sul River Watershed, Eastern São Paulo State (Figure 8), in order to provide a rapid and comprehensive understanding of hazard phenomena and their impacts, as well as to enable application of procedures of data integration and mapping in different socio-economic contexts (Andrade et al. 2010). The information was systematised and processed to allow the build-up of a geo-referenced database capable of providing information for both environmental regional planning (economic-ecological zoning) and local scale hazard mapping for civil defence purposes. The regional evaluation covered all the 34 municipalities located in the watershed, and comprised the following stages of work: 1) survey of previous flooding events reported in newspaper and historical archives; 2) data systematisation and consolidation to translate gathered news into useful pieces of technical information; 3) identification of flooding occurrence locations using Google Earth tools; 4) cartographic auditing, geo-referencing and spatial data analysis using a freeware GIS package called SPRING (see Section 5); 5) exploratory statistical analysis of data; 6) preliminary flooding hazard classification on the basis of statistical results. Such preliminary classification used geopolitical (municipality) and hydrographical sub-basin boundaries as units for the analysis.



A)

08/S2/R1 - Foto 2 - 27out2004 - Sadrak.
Talude de grande porte atrás da moradia.

Cadastro de Escorregamentos

Página 1 | Página 2 | Página 3

Código:
Município: Votorantim
Area_Setor: A8S2R1
Bairro: Sadrak
Acesso: R. Florêncio Vasquez (final da rua)
Coord N: 7394969 Coord E: 250629
alvenaria: ☑ madeira: ☐ outras: ☐
loc outras: padrão de ocupação muito bom)
UNIDADE DE ANÁLISE

B)

Fig. 7. A) Location of the City of Diadema in the Metropolitan District of São Paulo (State capital), Southeast Brazil and example of delineated risk zones over a high-resolution satellite image (Ikonos). B) Example of Map-Risk system display. See Section 4.2 for details. [after Marchiori-Faria et al., 2006; Pressinotti et al., 2007]

Fig. 8. Location of Paraiba do Sul River Watershed in Eastern São Paulo State and distribution of flooding occurrences. Internal sub-divisions correspond to geopolitical boundaries (municipalities). [After Andrade et al., 2010]

The regional evaluation was followed-up with detailed flooding hazard mapping (1:3,000 scale) in 7 municipalities, which included: a) ground observations - where previous occurrence was reported – to measure and record information on flooding height marks, land occupation, and local terrain, riverbank and water course characteristics; b) geo-referencing and spatial data analysis, with generation of interpolated numerical grids on flooding heights and local topography; c) data interpretation and delimitation of flooding hazard zones; d) cross-referencing of hazard zones with land use and economic information leading to delimitation of flooding risk zones. Numerical scoring schemes were devised for ranking hazard and risk zones, thus allowing relative comparisons between different areas. Hazard zone scores were based on intervals of flooding height (observed and interpolated) and temporal recurrence of flooding events. Flooding risk scores were quantified as follows: R = [H x (V x D)], in which potential damage and vulnerability were considered (housing areas, urban infrastructure, facilities and services to be affected) on the basis of image interpretation and cross-referencing with land use maps and information. A detail map (yet unpublished) showing the interpolated grid of flooding heights and delineated hazard zones is presented in Figure 9.

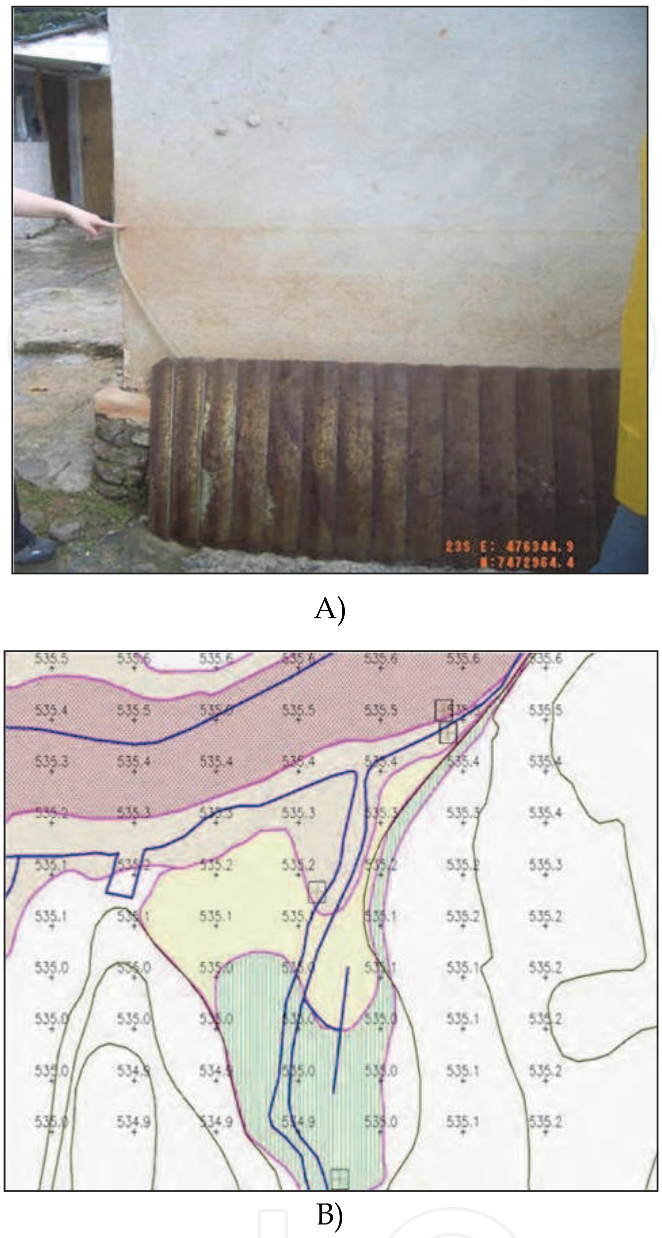


Fig. 9. A) Measurement of maximum flood height for recent flooding event. B) Numerical interpolated grid of flooding heights and delineated flooding hazard zones. Green = Low probability of occurrence, Estimated flooding heights (Efh) < 0.40 m. Yellow = Moderate probability, 0.40 < Efh < 0.80 m. Light Brown = High probability, 0.80 < Efh < 1.20 m. Red = Very high probability, Efh > 1.20 m. Ground observations and measurements: cross and rectangle. Continuous lines: black = topographic contour lines, blue = main river channel boundaries. Not to scale.

5. Geo-environmental assessment: applications to land reclamation policies

Land reclamation of sites of previous mineral exploitation frequently involve actions to minimize environmental damage and aim at re-establish conditions for natural balance and sustainability so reconciling former mined/quarried sites with their surroundings (Brollo et al., 2002). Strategies and programmes for land reclamation need to consider physical and biological characteristics of the local environment as well as socio-economic factors. Socio-environmental regeneration, involves not only revegetation and land stabilisation engineering, but also rehabilitation or introduction of a new function for the area.

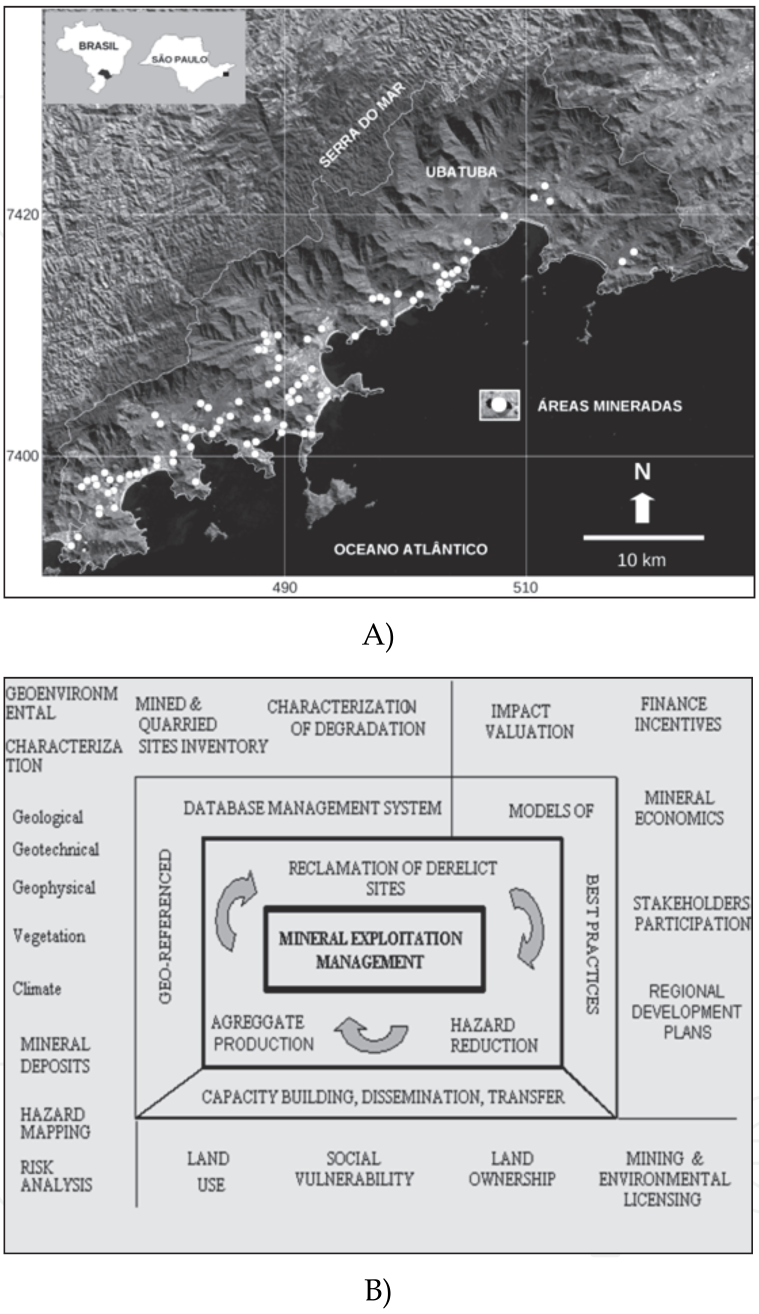


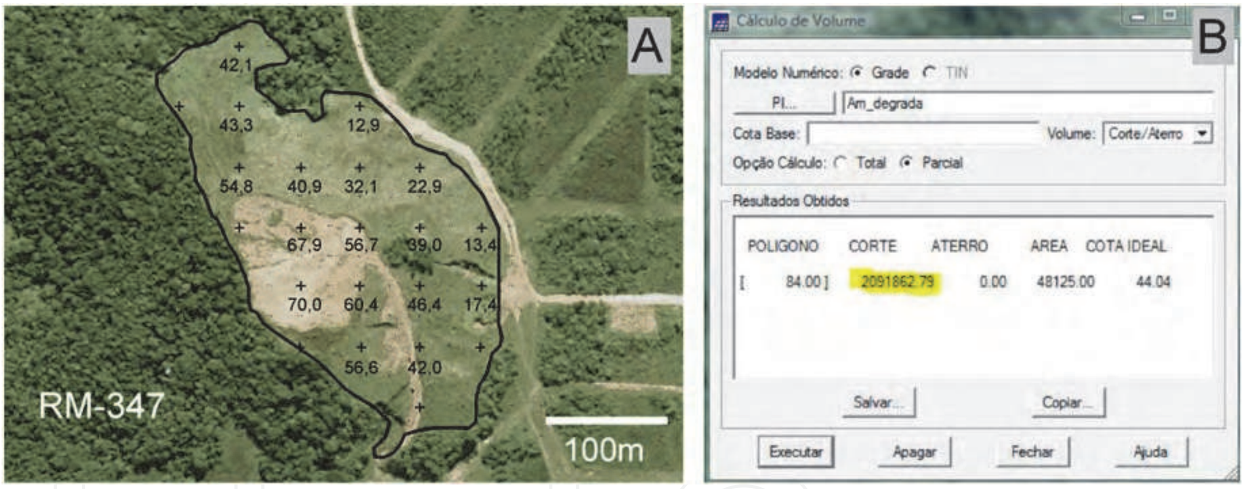
Fig. 10. A) Location map and satellite image of the Municipality of Ubatuba (North Shore São Paulo State, Southeast Brazil). Dots on image represent quarried/mined sites. B) Schematic display of the integrated approach taken to reconcile mineral exploitation management and land reclamation. The scheme shows the three main issues to be addressed (centre) and topics of interest to be studied. [after Ferreira et al., 2006; Ferreira & Fernandes da Silva, 2008]

The case study concerns a GIS-based geo-environmental management scheme to reconcile sustainable mineral exploration of aggregates and construction materials with regeneration of abandoned and/or derelict mined sites in the municipality of Ubatuba (North Shore of São Paulo State, Brazil). Until the early 1990's intensive exploitation of residual soil and ornamental stone (for fill and civil construction) took place in an unplanned and unregulated manner. This led to highly adverse environmental impacts, including the creation of 114 derelict and abandoned sites which resulted in State and Federal authorities enforcing a virtual halt to mining activity in the region. Besides this, the municipality of Ubatuba is highly regarded for its attractive setting and landscape, including encroached coastline with sandy beaches and bays with growing leisure and tourism activities. The area encompasses the Serra do Mar Mountain Range covered by large remnants of Atlantic Forest so that approximately 80% of the municipal territory lies within a nature and wildlife reserve (Figure 10A). As described by Ferreira et al. (2005, 2006), the devised strategy required an integrated approach (Figure 10B) in order to address three key issues: 1) environmental recovery of a number of derelict (abandoned, unsightly) sites; 2) reduction of hazards (land instability, erosion, flooded areas etc), particularly at those sites informally occupied by low income populations; and 3) rational exploitation of materials for local building materials corresponding to local needs. The study was implemented using a freeware GIS and image processing package called SPRING (Câmara et al. 1996, INPE 2009) and ortho-rectified air photos (1-metre resolution, taken in 2001, leading to an approximate scale of 1:3,000).

The key output of the land management strategy was a prioritisation ranking scheme based on a comprehensive site critical condition (ICR) score, which synthesised the significance of each factor or issue to addressed (IG/SMA, 2008; Ferreira et al., 2009). Accordingly, the score system consisted of three numerical indicators: 1) environmental degradation indicator (IDE), 2) mineral potential indicator (IPM), and 3) hazard/risk indicator (IRI). Each indicator was normalised to a scalar range (0 to 1), and the ICR was the sum of the three indicators. The ICR was then used to set up directives and recommendations to advise local and State authorities about the possible measures to be taken, through mid- and long-term policies and/or immediate remedial and mitigating actions.

According to Ferreira et al. (2008), the IDE comprised four component criteria to estimate the degree of adverse environmental impact (or degradation) of the individual mineral extraction sites: erosional features, terrain irregularity, herbaceous and bushy vegetation, and exposed soil. Information on these factors was acquired from imagery and ground checks. Tracing of linear features on images was investigated as an indicator of the frequency and distribution of erosional processes (rills, ravines, piping scars) as well as for terrain irregularity. In the first case, the sum of linear features representative of erosional processes was ratioed by the area of each site to quantify the estimate. Similarly, linear features related to the contour of cutting berms, rill marks, and slope breaks caused by mining/quarrying activity, were also measured to quantify terrain irregularity. The areal extent of herbaceous and bushy vegetation as well as exposed soil were also delimited on images.

The IPM, as described by Ferreira & Fernandes da Silva (2008), was achieved by means of the following procedures: 1) identification and delimitation of quarried/mined sites (polygons) on geo-referenced imagery; 2) derivation of local DEM (digital elevation model) from topographic contour lines to each delimited site; 3) calculation of local volume to material (V1) based on the original geometry of the quarried/mined sites; 4) calculation of volume of material already taken (V2) and exploitable volume of material (V3), so that [V3] = [V1 – V2]; 5) application of classification rules based on legal environmental and land use restrictions. The calculation of volumes of material (residual soil and ornamental stone) was performed by means of GIS operations involving polygons (areas) and numerical grids of topographic heights generated with nearest neighbour interpolator in the SPRING package (Figure 11). The IRI was derived from R = [H x (V x D)] – see Section 4.2 – focussing on mass movement and flood hazards and their consequences to people, property and economic activity. According to Rossini-Penteado (2007) and Tominaga et al. (2008), Hazard, H, was quantified according to the spatial and temporal probability of occurrence of each phenomenon and then weighted in relation to areal distribution of such probabilities (percentage of sq. km). The vulnerability, V, was computed by means of scores assigned to socio-economic aspects such as nature of built structures, spatial regularity of land occupation, presence of urban infrastructure (e.g. water supply, sanitation, health services, refuse collection and disposal method), road/street network, educational and income patterns. Similarly, in order to estimate the extent of potential damage, D, numerical scores were devised and attributed to the estimated number of people and buildings per unit area, and to the proportion of built area in relation to total area of the site.



```
Modelo Numérico: ● Grade ○ TIN
Am_degrada
Cota Base:                         Volume: Corte/Aterro
Opção Cálculo: ○ Total ● Parcial
Resultados Obtidos
  POLIGONO     CORTE        ATERRO    AREA       COTA IDEAL
[     84.00 ]  2091862.79   0.00      48125.00   44.04
```

Fig. 11. Example of the mineral potential indicator (IPM) for the Municipality of Ubatuba (North Shore São Paulo State, Southeast Brazil). A) Abandoned/quarried site delimited on image and numerical grid of topographic heights. B) Screen display from GIS-based computation of volumes of exploitable material [after Ferreira & Fernandes da Silva, 2008].

Figure 12 illustrates the application of the ICR scoring scheme to mined/quarried sites in Ubatuba. In summary, 47% of sites were classified as very low priority, 12% as low priority, 19% as moderate priority, 15% as high priority (18 sites), and 7% as very high priority (8 sites). The priorities represent a combination of availability of exploitable volumes of building materials and the need for measures to tackle adverse environmental impacts and high risk situations (Figure 12). Based on the application of the ICR scores and current land use, directives and recommendations for land reclamation and socio-regeneration of mined/quarried sites were consolidated into ten main groups (IG/SMA, 2008; Ferreira et al., 2009). Such directives and recommendations ranged from simple measures such as routine maintenance and cleaning, revegetation with grass and control of water surface flow (including run-off) to the implementation of leisure and multi-purpose public facilities, major land stabilisation projects combined with mineral exploitation, and monitoring.

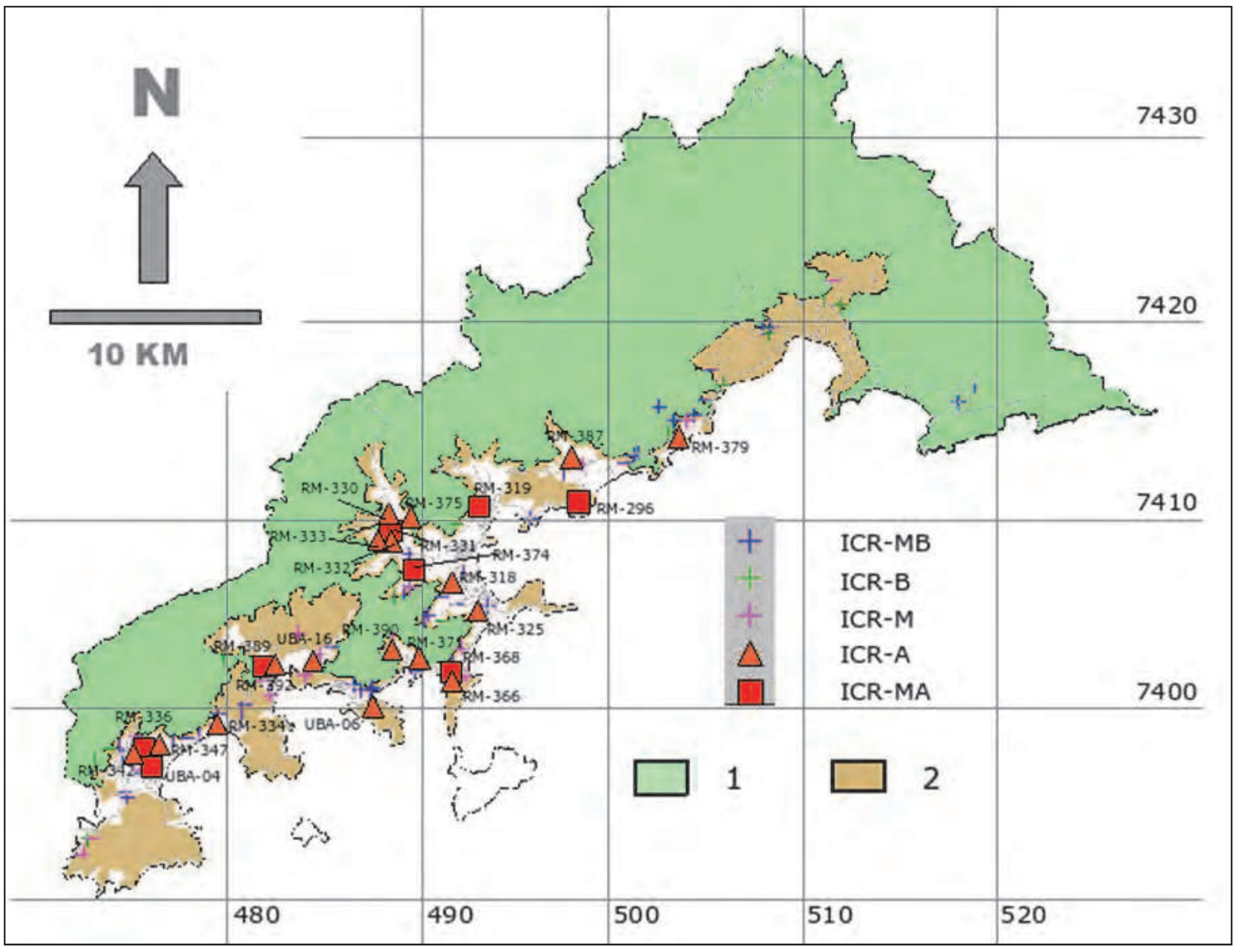


Fig. 12. Spatial distribution of mined/quarried sites classified according to critical condition score scheme (ICR). Sites classified as High (triangles) and Very High (squares) priority are highlighted. Remarks: 1- Serra do Mar Nature and Wildlife State Park, 2- Environmentally sensitive protected areas. ICR-MB = Very Low priority, ICR-B = Low priority, ICR-M = Moderate priority, ICR-A = High priority, ICR-MA = Very high priority [after IG/SMA, 2008].

6. Conclusions

Geo-environmental terrain classification may be used as part of the land-use planning decision making and may also provide the basis of responses to emergency situations. In most examples presented here, classification schemes were based on knowledge of the bedrock geology, topography, landforms, superficial geology (soil and weathered materials), groundwater conditions and land-uses. Information for the classification has been variously derived from remote sensing and fieldwork rather than specific site investigations. A framework for carrying out a terrain classification at different scales has been presented.

In practice, the effectiveness of land zoning system requires the implementation of planning controls. To do this the Local Authority needs adequate resources and an appropriate legal or planning guidance policy framework. Preferably, the control process should be based on the principle that permission will be given unless there is a good reason for refusal. In granting permission, conditions may then be applied to ensure the safety of the development with regard to landsliding, flooding and other potential problems. However it must be recognised that where practical control over development cannot be exercised, other preventive, mitigative or advisory measures may be all that can be used.

Marker (1996) explains that the rate and style of development has a major impact on the information requirements. Without a rigorously enforced planning framework based on accurate information about the ground conditions very rapid urban development will generally lead to construction on areas of less stable land or land which may be subject to hazards such as flooding or pollution. This type of development may also result in the sterilisation of geological resources which it would be expedient to exploit as part of the development process. On the other hand restricting development to designated areas will generally require detailed information about the ground conditions and likelihood and potential impact of hazards to be available at the planning stage. It also assumes existence of the resources and will to enforce the plan. Such models can severely constrain the social and economic development of an area, lead to excessively high population densities and give rise to problems associated with the re-use of previously developed land.

Policy formulation may incorporate incentives (e.g. subsidies and reduced taxes) to be provided by local and state governments to encourage such measures and good practice, which can be viewed as kinds of voluntary or induced control. In some cases financial controls exerted by public funding as well as mortgage and insurance providers are the means by which some types of development may be curtailed but such controls may not prevent informal occupancy of hazardous areas. In this regard, some of the examples presented here, from a regional and local perspective, have also demonstrated environmental management regulations may have little meaning in some urban areas subject to rapid expansion where, because of population influx, informal housing is virtually an inevitable consequence.

Due to the latter hazard mapping updating and post-episode monitoring [failure episodes] are absolutely vital as these procedures facilitate a contemporary understanding of ground conditions and risk circumstances, which can be essential to provide timely and efficient advice for mitigation and control of hazards as well as to design effective contingency actions and engineering solutions.

7. Acknowledgements

The authors are very much indebted to the Sao Paulo State Geological Institute and its staff for most of the examples provided here.

8. References

Akiwumi, F.A., Butler, D.R. (2008). Mining and environmental change in Sierra Leone, West Africa: a remote sensing and hydrogeomorphological study. *Environmental Monitoring Assessment*, 142: 309–318. ISSN 0167-6369

Alonso Herrero, E.; Frances, E., & Cendrero, A. (1990). Environmental geological mapping in Cantabrian Mountains, Spain. In: *Proceedings of the 6th Congress of the Intl.*

Assoc. Engineering Geology and Environment, Amsterdam. Balkema, Rotterdam, 1: 31-35.

Andrade, E.; Danna, L.C.; Santos, M.L., & Fernandes da Silva, P.C. (2010). Survey of flooding occurrence in newspaper records as a support for regional planning and hazard mapping. *Proceedings of 7th Brazilian Symposium on Geotechnical and Geo-environmental Cartography*. ISSN 2178-1834. Maringa, October 2010. 16p. [in Portuguese]

Aydin, F. (2002). Heterogeneity and behaviour of saprolitic slopes. *Proceedings of the 9th International Congress of the Intl. Assoc. Engineering Geology and Environment*, ISBN 0-620-28559-1, Durban, September 2002. p. 846-856.

Barton, J., Alexander, D., Correa, C., Mashelkar, R., Samuels, G., & Thomas S. (2002). Integrating intellectual property rights and development policy. London: UK Department for International Development, Commission on Intellectual Property Rights.

Beaumont, T.E. (1985). An application of satellite imagery for highway maintenance and rehabilitation in Niger. *International Journal of Remote Sensing*, 6 (7): 1263-1267, ISSN 0143-1161.

Beaumont, T.E. & Beaven, P.J. (1977). The use of satellite imagery for highway engineering in overseas countries. (T.R.R.L. - Transport & Road Research Laboratory) England, Supplementary Report 279, 19 p.

Beckett, P.H.T. & Webster, R. (1969). A Review of Studies on Terrain Evaluation by the Oxford-MEXE-Cambridge Group,1960-1969, MEXE Report 1123, Christchurch

Bell, F.G. (1993). *Engineering Geology*. Blackwell, Oxford. 269p.

Bennett, M.R & Doyle, P. (1997). *Environmental Geology*. John Wiley and Sons Ltd, Chicester.

Bourne, R. (1931). Regional Survey and its Relation to Stocktaking of the Agricultural Resources of the British Empire, Oxford Forestry Memoirs No.13.

Bowman, I. (1911). Forest Physiography, Physiography of the US and Principal Soils in Relation to Forestry, John Wiley and Sons, New York.

Brollo M.J., Barbosa, J.M., Rocha, F.T., & Martins, S.E. (2002). Research Programme on Characterisation and Reclamation of Environmentally Degraded Areas. *Proceedings of the 5th Meeting on Environmental Management Research*. São Paulo: CINP/SMA, 2002, p. 74-82. [in Portuguese]

Brollo, M.J., Vedovello, R., Gutjahr, M.R., Hassuda, S., Iritani, M.A., Fernandes da Silva, P.C., & Holl, MC. (2000). Criteria for selection of areas for waste disposal in regional scale (1:100,000). Application area: Metropolitan Region of Campinas, Sao Paulo State, Brazil. *Proceedings of the 8th Congress of the Intl. Assoc. Engineering Geology and Environment.* Vancouver, September 1998, 6: 4281-4286.

Brook D. & Marker B.R. (1987) Thematic geological mapping as an essential tool in land-use planning. In: Culshaw MG, Bell FG, Cripps JC, O'Hara M (eds) "*Planning and Engineering Geology*", Engineering Geology Special Publication No. 4. Geological Society, London, pp 211–214.

Câmara, G. & Fonseca, F. (2007) Information Policies and Open Source Software in Developing Countries. *Journal of the American Society for Information Science and Technology*, 58(1): 121–132, ISSN 1532-2890.

Câmara, G., Souza, R.C.M., Freitas, U.M., & Garrido, J. (1996). SPRING: Integrating remote sensing and GIS by object-oriented data modelling. *Computers & Graphics*, 20 (3): 395-403, ISSN 0097-8493.

Cendrero, A., Flor, G., Gancedo, R., González-Lastra, J.R., Omenaca, J.S., & Salinas, J.M. (1979). Integrated Assessment and Evaluation of the Coastal Environment of the Province of Vizcaya, Bay of Biscay, Spain. *Environmental Geology*, 2 (6): 321-331, ISSN 0943-0105.

Christian, C.S. (1958). The concepts of land units and land systems. In: *Proceedings of the 9th Pacific Science Congress*. Vol. 20, pp. 74-81.

Christian, C.S. & Stewart, GA. (1952). Summary of general report on Survey of Katherine - Darwin Region. CSIRO Land Research Series No.1

Christian, C.S. & Stewart, GA. (1968). Methodology of integrated surveys. *Proceedings of the Conference on Aerial Surveys and Integrated Studies*. UNESCO, Paris. pp. 233-280

Cripps, J.C., Fernandes Da Silva, P.C., Culshaw, M.G., Bell, F.G., Maud, R.R., & Foster, A. (2002). The planning response to landslide hazard in São Paulo State - Brazil, Durban - South Africa and Antrim - Northern Ireland. *Proceedings of 9th International Congress of the Intl. Assoc. Engineering Geology and Environment,* ISBN 0-620-28559-1, Durban, September 2002. p. 1841-1852.

Culshaw M.G., Foster, A., Cripps, J.C., & Bell FG (1990). Applied maps for land use planning in Great Britain. *Proceedings of the 6th International Congress of the Intl. Assoc. Engineering Geology and Environment.* AA Balkema, Rotterdam, 1: 85-93.

Culshaw M.G., & Northmore K.J. (2002) An engineering geological map for site investigation planning and construction type identification. In: Van Rooy JL, Jermy CA (eds) *Proceedings of the 9th International Association for Engineering Geology and the Environment Congress*, Durban, 423–431. South African Institute of Engineering and Environmental Geologists, Pretoria. On CD-ROM.

Culshaw M.G. & Price S.J. (2011) The 2010 Hans Cloos lecture: the contribution of urban geology to the development, regeneration and conservation of cities. *Bulletin of Engineering Geology and the Environment*, 70, Part 3. [In press]

Dai, F.C., Lee, C.F., & Zhang, X.H. (2001). GIS-based environmental evaluation for urban land-use planning: a case study. *Engineering Geology*, 61 (4): 257 – 271, ISSN 0013-7952.

Dearman, W.R. & Matula, M. (1977). Environmental aspects of engineering geological mapping. *Bulletin of the Intl. Assoc. Engineering Geology and Environment,* 14: 141-146. ISSN 1435-9529.

DOE - Department of the Environment. (1990). Development on unstable ground. Planning Policy Guidance PPG14, HMSO, London.

DOE - Department of the Environment. (1995) Development on unstable ground: Landslides and Planning. Planning Policy Guidance PPG14 Annex 1, HMSO, London.

Ellison, R. & Smith, A. (1998). Environmental Geology in Land Use Planning: Guide to the sources of earth science information for planning and development. Published by British Geological Survey (Nottingham, UK) on behalf of Department of Environment, Transport and the Regions, Great Britain.

Fernandes, A.J. (2003) The influence of Cenozoic Tectonics on the groundwater vulnerability in fractured rocks: a case study in Sao Paulo, Brazil. *Proceedings of the International Conference on Groundwater in Fractured Rocks*, Prague, IAH/UNESCO, p.81-82.

Fernandes, A.J. & Rudolph, D.L. (2001) The influence of Cenozoic tectonics on the groundwater-production capacity of fractured zones: a case study in Sao Paulo, Brazil. *Hydrogeology Journal*, 9: 151-167, ISSN 1431-2174.

Fernandes Da Silva, P.C., Cripps, J.C., & Wise, S.M. (2005a). The use of Remote Sensing techniques and empirical tectonic models for inference of geological structures: bridging from regional to local scales. *Remote Sensing of Environment*, 96 (1): 18 – 36. ISSN 0034-4257.

Fernandes da Silva, P.C., Ferreira, C.J., Fernandes, A.J., Brollo, M.J., Vedovello, R., Tominaga, L.K., Iritani, M.A., & Cripps, J.C. (2005b). Evaluation of land instability and groundwater pollution hazards applying the physiographic compartmentalisation technique: case study in the Metropolitan District of Campinas, Brazil. *Proceedings of the 11th Brazilian Congress on Environmental and Engineering Geology*, ISBN 85-7270-017-X. Florianopolis, November 2005. Pp. 383 – 402. [In Portuguese]

Fernandes da Silva, P.C., Maffra, C.Q.T., Tominaga, L.K., & Vedovello, R. (1997a). Mapping units on São Sebastião Geohazards Prevention Chart, Northshore of São Paulo State, Brazil. In: *Environmental Geology, Proceedings of the 30th International Geological Congress*. Daoxian, Y. (Ed.), 24: 266-281, VSP Scientific Publisher, ISBN 90-6764-239-8. Utrecht.

Fernandes da Silva, P.C., Moura-Fujimoto, N.S.V., Vedovello, R., Holl, M.C., & Maffra, C.Q.T. (1997b). The application of structural geological data in mass movement hazard zoning at the municipality of São Sebastião, Northshore of São Paulo State, Brazil. *Proceedings of the 6th Brazilian Symposium on Tectonic Studies*, Goiania, May 1997. p. 136-138. [in Portuguese]

Fernandes da Silva, P.C., Vedovello, R., Ferreira, C.J., Cripps, J.C., Brollo, M.J., & Fernandes, A.J. (2010) Geo-environmental mapping using physiographic analysis: constraints on the evaluation of land instability and groundwater pollution hazards in the Metropolitan District of Campinas, Brazil. *Environmental Earth Sciences*, 61: 1657–1675. ISSN 1866-6280.

Ferreira, C.J.; Brollo, M.J.; Ummus, M.E.; & Nery, T.D. (2008). Indicators and quantification of environmental degradation in mined sites, Ubatuba (SP). *Revista Brasileira de Geociências*, 38(1): 141-152. ISSN 0375-7536 [In Portuguese]

Ferreira, C.J. & Fernandes da Silva, P.C. (2008). The use of GIS for prioritising mineral exploitation of building materials in derelict sites: the Ubatuba – SP case. *Revista do Instituto Geológico*, 29 (1/2): 19-31. ISSN 0100-929X [In Portuguese]

Ferreira, C.J., Fernandes da Silva, P.C., & Brollo, M.J. (2009). Directives for socio-regeneration of sites affected by mining activity, Ubatuba, Sao Paulo State. *Proceedings of the 11th Southeast Brazil Geological Symposia*, ISSN 2175-697X, São Pedro, November 2009. pp. 123-124.

Ferreira, C.J., Fernandes da Silva, P.C., Brollo, M.J., & Cripps, J.C. (2006). Dereliction problems from exploitation of residual soil and ornamental stone at Sao Paulo

State, Brazil. *Proceedings of the 10th International Congress of the International Association of Engineering Geology and Environment*. Nottingham , September 2006. CD-ROM. 10p.

Ferreira, C.J., Fernandes da Silva, P.C, Furlan, S.A., Brollo, M.J., Tominaga, L.K., Vedovello, R., Guedes, A.C.M., Ferreira, D.F., Cripps, J.C., & Perez, F. (2005). Devising strategies for reclamation of derelict sites due to mining of residual soil (Saibro) at Ubatuba, North coast of Sao Paulo State, Brazil: the views and roles of stakeholders. *Sociedade e Natureza* , Special Issue on Land Degradation, p.643 - 660, ISSN 0103-1570.

Finlayson, A. (1984). Land surface evaluation for engineering practices: Applications of the Australian P.U.C.E. system for terrain analysis. *Quarterly Journal of Engineering Geology*, 17(2): 149-158, ISSN 1470-9236

Grant, K. (1968). A Terrain Evaluation System for Engineering. CSIRO, Div. Soil. Mech. Technical Paper No. 2, Melbourne. 27p.

Grant, K. (1974). The PUCE Programme for Terrain Evaluation System for Engineering Purposes. II. Procedures for Terrain Classification. CSIRO, Div. Soil. Mech. Technical Paper No. 15, Melbourne. 68p.

Grant, K. (1975). The PUCE Programme for Terrain Evaluation System for Engineering Purposes. I. Principles. CSIRO, Div. Soil. Mech. Technical Paper No. 19, Melbourne. 32p.

Griffiths, J.S. & Edwards, R.J.G. (2001). The development of land surface evaluation for engineering practice. In Griffiths, J S (Ed.) Land Surface Evaluation for Engineering Practice. Geological Society, London, Engineering Geological Special Publication, 18, 3 – 9.

Griffiths, J S (Ed.) 2001 Land Surface Evaluation for Engineering Practice. Geological Society, London, Engineering Geological Special Publication, 18.

Guy, M. (1966). Quelques principles et quelques experiences sur la metodhologie de la photointerpretation. *Proceedings of the 2nd International Symposium on Photo-interpretation*. Paris, 1966. v.1: 2-41.

Hill, S.E. & Rosenbaum, M.S. (1998). Assessing the significant factors in a rock weathering system. Quarterly Journal of *Engineering Geology*, 31: 85-94, ISSN 0013-7952.

Howard, A.D. (1967) Drainage analysis in geologic interpretation: a summation. *Bulletin of the American Association of Petroleum Geologists*, 51: 2246-2254, ISSN 0149-1423.

Hudec, P.P. (1998) Rock properties and physical processes of rapid weathering and deterioration. *Proceedings of the 8th International Congress of the Intl. Assoc. Engineering Geology and Environment*, Vancouver, September 1998. p.335-341.

IG/SMA – Instituto Geológico/ São Paulo State Secreariat of Environmet. (1996). São Sebastião Geohazards Prevention Chart, Northshore of São Paulo State, Brazil. São Paulo, Technical Report, 77p. [in Portuguese]

IG/SMA - Instituto Geológico/ São Paulo State Secreariat of Environmet. (1999). Methodology for Selection of Suitable Areas for Treatment and Disposal of Solid Waste: Regional Approach. São Paulo, IG/SMA Technical Report, 98p. [in Portuguese]

IG/SMA - Instituto Geológico/ São Paulo State Secreariat of Environmet. (2003). Evaluation of land instability and groundwater pollution hazards in the Metropolitan District of Campinas, Brazil. São Paulo, Foreign Commonwealth Office Intl. Cooperation Programme. Technical Report, 57p.

IG/SMA - Instituto Geológico/ São Paulo State Secreariat of Environmet. (2008). Directives for Socio-Environmental Regeneration of Derelict Sites Due to Mining of Building Materials, Ubatuba, Northshore of São Paulo State, Brazil. São Paulo, FAPESP – Public Policies Research Programme, Funding Grant n. 03/07182-5. Final Tech. Sci. Report, 168p. [in Portuguese]

INPE - Brazilian National Institute for Space Research (2009) SPRING 5.0. http://www.dpi.inpe.br/spring/english/download.php. Cited in 11 December 2009.

Kiefer, R.W. (1967). Terrain analysis for metropolitan fringe area planning, *Journal of the Urban Planning and Development Division, Proceedings of the American Society of Civil Engineers,* UP4, 93, 119-39.

Latifovic R., Fytas K., Chen J., & Paraszczak J. (2005) Assessing land cover change resulting from large surface mining development. *International Journal of Applied Earth Observation and Geoinformation*, 7: 29–48, ISSN 0303-2434.

Lillesand, T. & Kiefer, R.W. (2000) Remote Sensing and Image Interpretation. 4th Ed., John Wiley, New York.

Mabbut, J.A. 1968. Review of concepts on land classification. In: *Land Evaluation*. Stewart, G.A. (ed.), p. 11-28, Macmillan, Melbourne.

Marchiori-Faria, D.G., Ferreira, C.J., Fernandes da Silva, P.C., Rossini-Pentado, D., & Cripps, J.C. (2006). Hazard mapping as part of Civil Defence preventative and contingency actions: A case study from Diadema, Brazil. *Proceedings of the 10th International Congress of the International Association of Engineering Geology and Environment*. Nottingham , September 2006. CD-ROM. 10p.

Marker, B.R. (1996). Role of the earth sciences in addressing urban resources and constraints In: McCall, G J H ; de Mulder, E F J and Marker, B R (Eds). *Urban Geoscience*. AGID Special Publication Series No 20 in association with Cogeoenvironment. Balkema (Rotterdam), pp 163-180.

Matula, M. (1979). Regional engineering geological evaluation for planning purposes. *Bulletin of the Intl. Assoc. Engineering Geology and Environment,* 18: 18-24. ISSN 1435-9529

Matula, M. & Letko, V. (1980). Engineering geology in planning the metropolitan region of Bratislava. *IAEG Bull.,. Bulletin of the Intl. Assoc. Engineering Geology and Environment,* 19: 47-52. ISSN 1435-9529

Meijerink, A.M. (1988). Data acquisition and data capture through terrain mapping units. *ITC Journal,* International Journal of Applied Earth Observation and Geoinformation 1: 23-44. ISSN 03032434

Miliaresis, G.Ch. (2001). Geomorphometric mapping of Zagros Range at regional scale. *Computer and Geosciences*, 27 (7): 775 – 786. ISSN 0098-3004.

Mitchell, C.W. (1991). *Terrain Evaluation*. 2nd Ed. Longman, Essex. 497p.

Moura-Fujimoto, N.S.V., Holl, M.C., Vedovello, R., Fernandes da Silva, P.C, & Maffra, C.Q.T. (1996). The identification of mass movement hazard zones at the municipality of São Sebastião, Northshore of São Paulo State, Brazil. *Proceedings of the 2nd Brazilian Symposium on Geotechnical Cartography*. São Paulo, November 1996. p. 129-137. [in Portuguese]

Nedovic-Budic, Z. (2000). Geographic Information Science Implications for Urban and Regional Planning. *URISA Journal*, 12(2): 81-93. ISSN 1045-8077.

Pine, R.J. & Harrison, J.P. (2003). Rock mass properties for engineering design. *Quarterly Journal of Engineering Geology and Hydrogeology*, 36: 5–16. ISSN1470-9236.

Porcher, M. & Guillope, P. (1979). Cartographie des risques ZERMOS appliquées a des plans d'occupation des sols en Normandie. Bull. Mason Lab. des Ponts et Chausses, 99.

Pressinotti, M.M.N., Guedes, A.C.M, Fernandes da Silva, P.C, Sultanum, H.J., & Guimarães, R.G. (2007). Automated system for displaying of gravitational mass movement and flooding hazard mapping of São Paulo State. *Proceedings of the 6th Brazilian Symposium on Geotechnical and Geo-environmental Cartography.* Uberlândia, November 2007. p. 324 – 333. [in Portuguese]

Pressinotti, M.M.N, Fernandes da Silva, P.C.; Marchiori-Faria, D.G., & Mendes, R.M. (2009). The experience of the Geological Institute in hazard maping and risk analysis in urban environments. *Proceedings of the 11th Southeast Brazil Geological Symposia*. São Pedro, November 2009. ISSN 2175-697X. P. 156-157. [in Portuguese]

Rossini-Penteado, D., Ferreira, C.J., & Giberti, P.P.C. (2007). Quantification of vulnerability and potential damage applied to hazard mapping and risk analysis, 1:10,000, Ubatuba-SP. *Proceedings of the 2nd Brazilian Symposium on Natural and Technological Disasters.* Santos, December 2007. [in Portuguese]

Sabins Jr., F.F. (1987). *Remote Sensing. Principles and Interpretation.* Freeman, New York.

Soares, P.C. & Fiori, A.P. (1976). Systematic procedures for geological interpretation of aerial photographs. Notícia Geomorlógica 16 (32): 71-104. [In Portuguese]

Soares, P.C., Mattos, J.T., Barcellos, P.E., Meneses, P.R., & Guerra, S.M.S. (1981). Regional morpho-structural analysis on Radar and Landsat images at the Parana Basin. *Proceedings of the 3rd South Brazilian Regional Symposium on Geology*, Curitiba. p. 5-23. [In Portuguese]

Thompson, A., Hine, P.D., Poole J.S. & Greig, J.R. (1998a) Environmental Geology in Land Use Planning: Advice for planners and developers. Published by Symonds Travers Morgan (East Grinstead, UK) on behalf of Department of Environment, Transport and the Regions, Great Britain.

Thompson, A., Hine, P.D., Poole J.S. & Greig, J.R. (1998b) Environmental Geology in Land Use Planning: A guide to good practice. Published by Symonds Travers Morgan (East Grinstead, UK) on behalf of Department of Environment, Transport and the Regions, Great Britain.

Thompson, A., Hine, P.D., Greig, J.R. & Poole J.S. (1998c) Environmental Geology in Land Use Planning: Emerging issues. Published by Symonds Travers Morgan (East Grinstead, UK) on behalf of Department of Environment, Transport and the Regions, Great Britain.

Thornton, S.F., Lerner, D.N., & Banwart, S.A. (2001) Assessing the natural attenuation of organic contaminants in aquifers using plume-scale electron and carbon balances: model development with analysis of uncertainty and parameter sensitivity. *Journal of Contaminant Hydrology*, 53(3-4): 199-232. ISSN 0169-7722.

Tominaga, L.K., Rossini-Penteado, D., Ferreira, C.J., Vedovello, R. & Armani, G. (2008). Landsliding hazard assessment through the analysis of multiple geo-environmental factors. *Proceedings of the 12th Brazilian Congress on Environmental and Engineering Geology*. ABGE, ISBN 978-85-7270-052-8. Porto de Galinhas, November 2008. 15p. [In Portuguese]

Tominaga, L.K. (2009a). Natural Disasters: Why they happen ? In: *Disasters: Knowing to prevent.* Tominaga, L.K., Santoro, J., & Amaral, R (eds). Pp. 147-160, Geological Institute, ISBN 978-85-87235-09-1, São Paulo. [In Portuguese]

Tominaga, L.K. (2009b). Risk Analysis and Mapping. In: *Disasters: Knowing to prevent.* Tominaga, L.K., Santoro, J., & Amaral, R (eds). Pp. 13-23, Geological Institute, ISBN 978-85-87235-09-1, São Paulo. [In Portuguese]

TRRL - Transport & Road Research Laboratory. (1978). Terrain evaluation for highway engineering and transport planning: a technique with particular value for developing countries. TRRL Supplementary Report No. 448, 21p.

UN-ISDR – United Nations – International Strategy for Disaster Reduction. (2004). Living with Risk: A Global Review of Disaster Reduction Initiatives. In: *Inter-Agency Secretariat International Strategy for Disaster Reduction*. Geneve, 152p. Accessed in Aug, 2009. Available at http://www.unisddr.org.

Varnes, D.J. (1984). *Landslide Hazard Zonation: Review of Principles and Practice*. Unesco Press, Paris, 56p.

Vedovello, R. (2000). *Geotechnical Zoning for Environmental Management through Basic Physiographic Units.* (unpublished PhD Thesis, Sao Paulo State University at Rio Claro). [In Portuguese]

Vedovello, R. (1993). *Geotechnical Zoning based on Remote Sensing Techniques for Urban and Regional Planning.* São José dos Campos, 186p. (unpublished M.Sc. Dissertation, National Institute for Space Research) [In Portuguese]

Vedovello, R. & Mattos, J.T. (1998). The use of basic physiographic units for definition of geotechnical units: a remote sensing approach. *Proceedings of the 3rd Brazilian Symposium on Geotechnical Cartography.* São Paulo, November 1998, 11p. [In Portuguese]

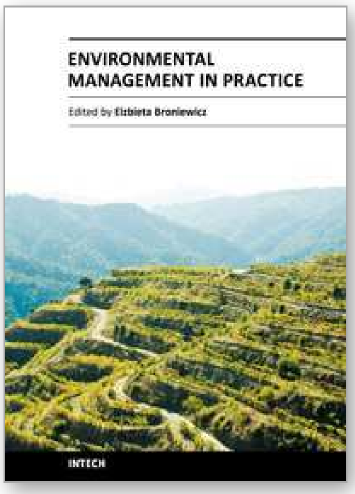
Vedovello, R., Brollo, M.J., & Fernandes da Silva, P.C. (1998). Assessment of erosion as a conditioning factor on the selection of sites for industrial waste disposal: an approach based on regional physiographic compartmentalisation obtained from satellite imagery. *Proceedings of the 3rd Brazilian Symposium on Erosion Control.* Presidente Prudente, March 1998. 9p. [In Portuguese]

Vedovello, R., Tominaga, L.K., Moura-Fujimoto, N.S.V., Fernandes da Silva, P.C., Holl, M.C., & Maffra, C.Q.T. (1997). A mass movement hazard analysis approach for public authority responses. In: *Proceedings of the 1st Latin American Forum on Applied Geography.* Curitiba, September 1997. 9p. [In Portuguese]

Verstappen HTh (1977) *Remote Sensing in Geomorphology*. Elsevier Sci. Publ., Amsterdam. 214p.

Vinogradov, B.V., Gerenchuk, K.I., Isachenko, A.G., Raman, K.G., & Teselchuk, Y.N. (1962). Basic principles of landscape mapping, Soviet Geography: Review and Translation, 3 (6), 15-20.

Vrba J. & Civita, M. (1994) Assessment of groundwater vulnerability. In: *Guidebook on Mapping Groundwater Vulnerability*. Vrba, J. & Zaporozec, A. (eds.). 16: 31-48, International Association of Hydrogeologists (IAH).



Environmental Management in Practice
Edited by Dr. Elzbieta Broniewicz

ISBN 978-953-307-358-3
Hard cover, 448 pages
Publisher InTech

Published in print edition June, 2011

In recent years the topic of environmental management has become very common. In sustainable development conditions, central and local governments much more often notice the need of acting in ways that diminish negative impact on environment. Environmental management may take place on many different levels - starting from global level, e.g. climate changes, through national and regional level (environmental policy) and ending on micro level. This publication shows many examples of environmental management. The diversity of presented aspects within environmental management and approaching the subject from the perspective of various countries contributes greatly to the development of environmental management field of research.

Paulo Cesar Fernandes da Silva and John Canning Cripps (2011). Geo-environmental Terrain Assessments Based on Remote Sensing Tools: A Review of Applications to Hazard Mapping and Control, Environmental Management in Practice, Dr. Elzbieta Broniewicz (Ed.), ISBN: 978-953-307-358-3, InTech, Available from: http://www.intechopen.com/books/environmental-management-in-practice/geo-environmental-terrain-assessments-based-on-remote-sensing-tools-a-review-of-applications-to-haza

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821