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FROM ZONING TO TERRITORIAL ENVIRONMENTAL MANAGEMENT: ENVIRONMENTAL VULNERABILITY MAPPING TO THE MINING IMPACTS IN MINAS GERAIS NORTHERN REGION – BRAZIL

Do Zoneamento à Gestão Ambiental Territorial: mapeamento de vulnerabilidade ambiental à mineração na Região Norte de Minas Gerais

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ABSTRACT

The environmental impacts of sand mining in hillsides of the North of Minas Gerais State have led to social unrests, discussed at Minas Gerais State North Regional Collegiate Unity of the State Council of Environmental Policy – COPAM. Aiming at better supporting the discussions and bringing about proposals to the conflict resolution, an environmental vulnerability zoning related to such undertakings was elaborated. This zoning considered variables derived from topography, land use, ecosystems and from the synergy of those impacts on the hydrographic network. Means to achieve the sustainable development of the mining works aiming at the civil construction industry are suggested after analyzing the obtained product.

Keywords: Environmental zoning, mining, GIS, environmental license.

RESUMO

Os impactos ambientais das minerações de areia de encosta na Região Norte de Minas têm levado a crescentes conflitos sociais, com ressonância na Unidade Regional Colegiada do Norte de Minas, do Conselho Estadual de Política Ambiental – Copam. Como forma de trazer melhores subsídios para a discussão, e com o intuito de trazer propostas para solucionar os conflitos, foi realizado um zoneamento referente à vulnerabilidade aos impactos ambientais desses empreendimentos. O zoneamento incorporou variáveis derivadas da topografia, do uso do solo, dos ecossistemas e da sinergia de impactos na rede hidrográfica. A partir dos produtos obtidos, propõem-se caminhos para conduzir ao desenvolvimento sustentável da mineração de construção civil na região.

Palavras-chave: Zoneamento Ambiental, Mineração, Geoprocessamento, Licenciamento Ambiental.

1 INTRODUCTION

The socio-economic development of northern Minas Gerais is polarized between the agricultural production (50% of the economically active population), and the extractive and transformation industry of non-metallic minerals (18% of the collected State Goods and Services Tax) according to ECOPLAN (2009). Therefore, it is clear the need to prepare planning and management mechanisms to regulate the dependence of both activities towards natural resources.

Sand mining for constructions in Serra Velha (along BR-135 highway, which limits Bocaiuva and Montes Claros counties) has been responsible for socio-environmental conflicts due to the significant deterioration of slopes and waterways draining the area. Extractors of sand, in turn, argue that their undertakings are essential to the development of the region and, therefore, their activities cannot be simply stopped.

The Minas Gerais State North Regional Collegiate Unity (URC), linked to the State Council for Environmental Policy (COPAM), has been the venue for the settlement of conflicts. As a proposal to resolve the issue, IBAMA was in charge to implement an environmental zoning aiming at bringing about the required technical groundings for sand mining, so that a more appropriate regional planning for the sustainable development of the region could be achieved.

The vulnerability to mining operations was presented within this context, including its suitability for sand mining, erosion and protection of the river environments. Field data, remote sense databases, geomorphological and geological surveys were used, as well as, official cartographical databases. A comprehensive zoning plan was presented for the Urucuia Sandstone along the Sao FranciscoRiver right bank (east), and a detailed zoning for the region of Serra Velha.

1.1 Localization

Serra Velha is the focus of the analyzed conflicts, but sand mining in the north portion of Minas Gerais state involves a wider regional chain than Serra Velha focus. Any punctual solution addressing Serra Velha most likely will just transfer the projects to other areas where new trouble spots would be created. The 2003/2004 moratorium on sand mining in Montes Claros County has shown that the mining conflicts were partially transferred to the neighbor counties. It has also created economic and political impasses because of the negative impact on the construction industry. A coherent solution to solve the mining issue related to building activities should include a regional planning to ensure the environment preservation along with the sustainable development required by economic sectors of the construction industry.

This is why we decided to analyze Serra Velha in the spatial context of the geological occurrence of sandstone coverage within the micro-region of Montes Claros. The location map shown in Figure 1 exhibits the Urucuia Sandstone occurrences crossing 23 municipalities from Montes Claros County to the riverbanks of the Sao Francisco. Therefore, this study was set out to investigate the whole Urucuia sandstone area along the right bank (east) of the Sao FranciscoRiver, including site details of the mining works in Serra Velha (Figure 2).

1.2 Regional features

1.2.1 Geology

According to CPRM (Mineral Resources Research Company) geological surveys, the section of Serra Velha between Montes Claros and Bocaiuva consists of sandstones from the Urucuia Formation (COSTA et al., 1975), having coarse albeit well-selected structure, probably due to old deflation surfaces (FEBOLI, 1985). Some finer grained river sandstones (SOARES et al., 2002) can be seen in the top stratigraphic levels of the formation.

Lutites from Bambui Group are placed beneath the sandstone (HEINECK, 1971 – identified as metapelites by SOARES et al. 2002) forming a layer of silty-clay matrix metamorphic rocks of low permeability. Soares et al. (2002) based on field surveys have suggested that this geological framework might be applied to the Urucuia sandstone coverage as a general model for the Montes Claros region. The flatter topography of the residual sandstone plateau, along with the typical porosity of the rock matrix, helps the rainwater seep through the sandstone and feed the hillside water sources (SOARES et al. 2002) which usually happens where the

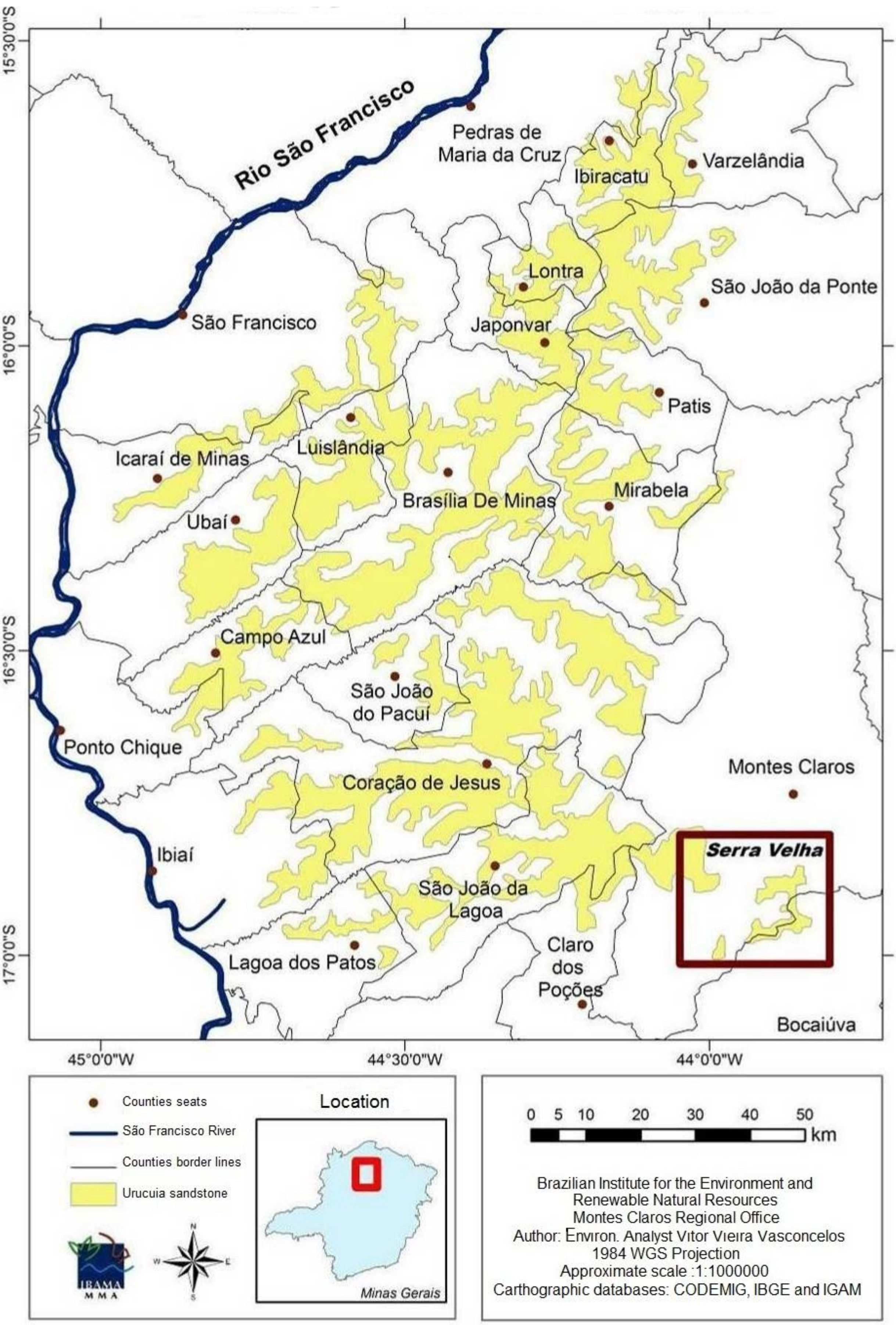

Figure 1: Location map of the Urucuia Sandstone Sedimentary Plateau at the right bank (east) of the Sao Francisco River - North of Minas Gerais.

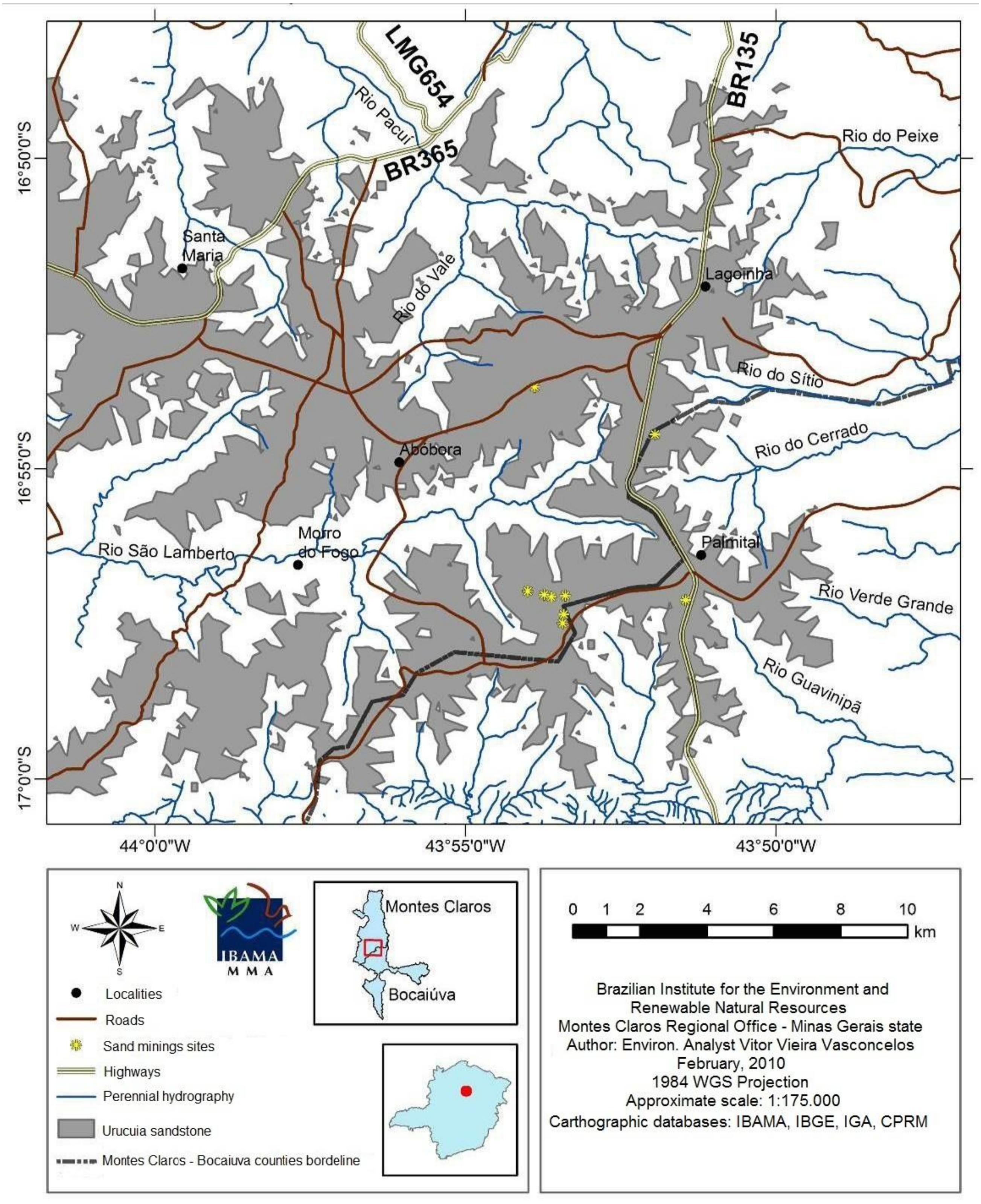

Figure 2: Location map of Serra Velha in Montes Claros and Bocaiuva Counties – Minas Gerais state.

sandstone lithostratigraphy makes surface contact with the metapeliteslithostratigraphy.

Debris-Lateritic surfaces originated from mud, ferrous concretions, sand and laterite can be found in some spots above the Urucuia sandstone (LEITE, 2008).Gravel extractions to be used in road constructions, either paved or unpaved, are usually found on such sites

(PEREIRA, 1984; GESCOM, 2008). Although gravel pits are beyond the scope of this work, it's worth to emphasizethat runoff changes from all existing mines on slopes should be considering on the environmental impact analysis of a sub-basin. However, it should be stressed that extracting sand instead of gravel generally brings about higher impacts due to the lesser stability of the sandpit slopes and to its greater contribution to the silting of the watercourses.

1.2.2 Erosion vulnerability

The Urucuia sandstone residual plateau on the right bank (east) of the São Francisco River is at an altitude range of 524 to 1,181 meters above sea level. The plateau eastern limit has an abrupt rising towards the urban perimeter of the city of Montes Claros. After such steep rising, the plateau smoothly dips to the west towards the San FranciscoRiver.

From a geological point of view, such relief conformation can be explained assuming an event of progressive deformation and heterogeneous tectonic transport from east to west, with an increased and gradual deformation towards the west (OLIVEIRA, 1989).Such tectonic transport was responsible for the contact thrust fault between groups Macaúbas and Bambuí (FEBOLI, 1985) beginning in JuramentoCounty and continuing towards north up to the city of Janauba. Later there was a negative cambering of the São Francisco Craton (so called by Feboli in 1985 as a syneclise type basin), which lowered along the São Francisco riverbed causing the residual plateau dipping towards west. Simultaneously, the erosion continued its intensive work, which went on dissecting the plateau edges from east to west, starting from the thrust fault and eroding it up to the current ridge slopes on the west of the city of Montes Claros.

Studies by Pereira (1984), Araujo et al. (1995), and Leite (2008), from field data and cartographic integrating models were used to zone regions covering the study area, and focusing on their erosive potential. These three studies have also included specific information about the area covered by the Urucuia sandstone and regarding Serra Velha region.

Pereira's study in 1984 employs a geosystemic approach to analyze erosive processes in the northern region of Minas Gerais. He used the geological, topographical and vegetation basic data to accomplish this, as well as extensive field work during his investigation of the regional geomorphological processes. According to Pereira (1984), the areas of greatest weakness in relation to erosion are the fluvial dissecting systems limits advancing towards the residual flattened plains of the Sao Francisco Basin. The author calls these fronts areas of instability, characterized by abrupt relief breaks which causes the plateau geosystem to lose its morphodynamic balance as it tries to find new stability. Until it becomes a relatively stable area of rolling hills, an intense erosion occurs at the site.

Pereira (1984) points out that those fronts of instability require a particular concern with areas upstream of resurgences. Surges are a consequence of surface and subsurface runoff that lead to the leverage of slopes due to erosion. To illustrate the interrelationship among surges, geology, geomorphology and erosion of slopes in the northern region of Minas Gerais, we have adapted the geomorphological schemes from Pereira (1984) in Figure 3. The typical location of sandpits in the Urucuia sandstone is on the upper slope surges types 1 and 2 of the Figure 3. Thus, from a geosystemic point of view, mining on these hillslopes already has a significant erosive potential.

Pereira (1984) recommends special attention to the erosion of Veredas (Brazilian Savanna wetlands) near the foot of the slopes. These Veredas are deemed possible geoindicators for the whole nearby area due to the specific hydrogeologic land geomorphological processes leading to their formation. The author base his recommendation on the grounds of the researches on erosion Veredas carried out by

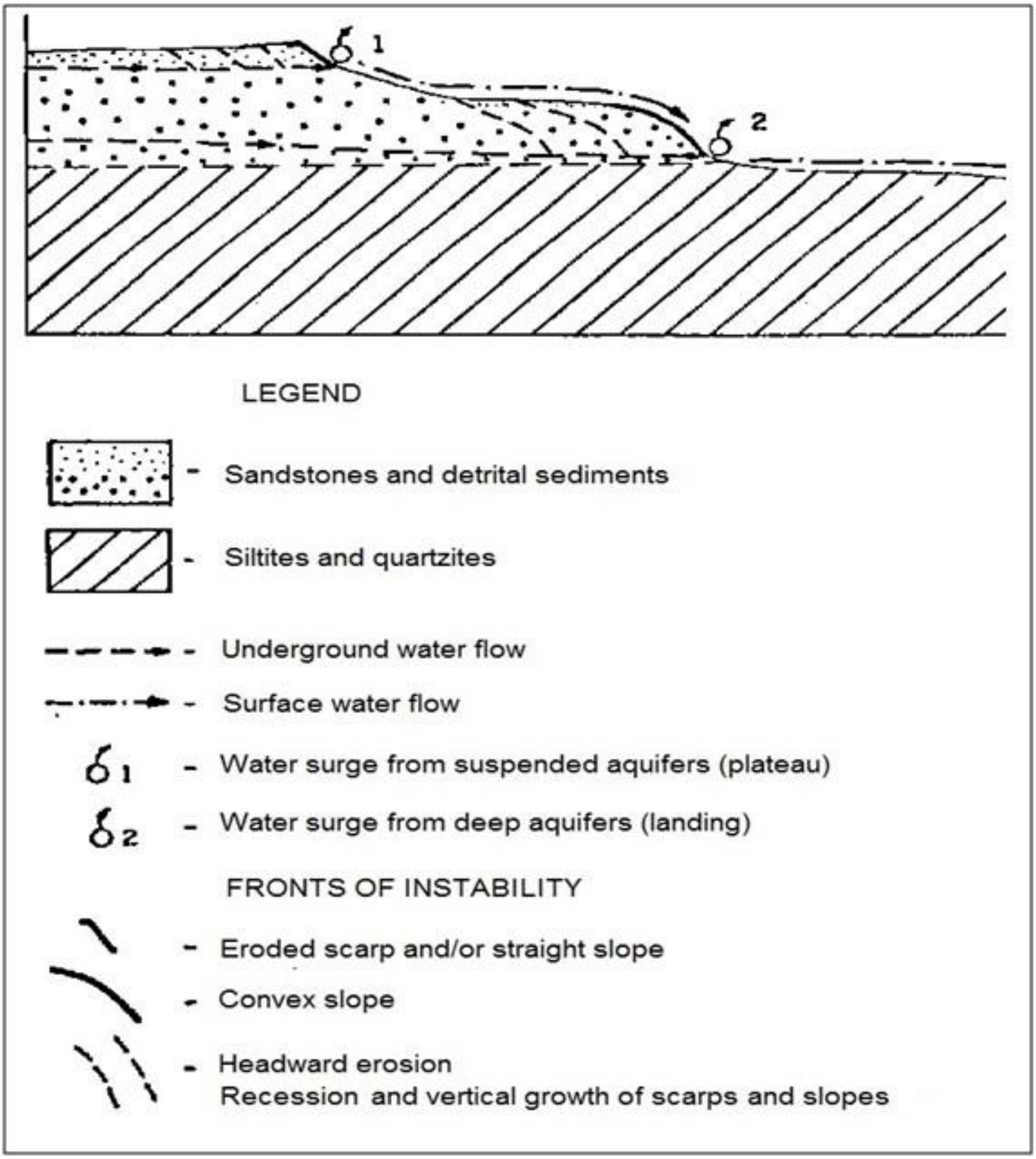

Figure 3: Schematic profile of the evolution of slopes in sandstone plateaus in the North of Minas Gerais. Adapted from Pereira (1984).

Boaventura (1978a, 1978b and 1983).

Leite (2008) uses Ross' methodology (1991, 1992 and 1994) to combine the potential fragility of erosion with the degree of protection / fragility of land use in the city of Montes Claros. The erosion potential was calculated through the analysis of the slope shape, its topographic location, interfluvialwidth and erosive potential of soils. The protection / fragility of the land is referred to the relationship of the vegetation (or lack thereof) in the processes of water conservation and soil.

Leite analyses result of 2008 allow the inference of significant environment fragility on the remaining edges of the Serra Velha plateau. Leite's mapping and land use study (2008) specifically emphasize the significant presence of exposed soil in Serra Velha (on the county southeast) standing out its actual environmental degradation.

Araujo et al. (1995) uses Lima et al. methodology (1992) to evaluate the erosion risk in Serra Velha. After combining geological, slope, mean annual precipitation, pedology and land cover data, he classified some sandy soil in Serra Velha with significant slope (more than 5%) and anthropogenic modification of vegetation cover as high-risk erosion areas (Araujo et al. 1995, p. 558). Considering that Serra Velha soils are typically inceptisols (leptosols) and quartziticpsamments(arenosols) according to GESCOM (2008) survey, with oxisols (latosols) spots over a sandstone saprolite local mantle, and noting that Leite (2008) mapped a significant amount of exposed soil in this region, we can infer the prevalence of these high-risk erosion areas in the Serra Velha slopes.

The rainfall data for the region show an annual rainfall above 1,300mm per year (ECOPLAN, 2009). However, most of the year the Atlantic Equatorial Mass (mEa) has a stabilizing influence into the region causing long droughts (OLIVEIRA, 2007). Almost all rainfall volume concentrates in November, December and January, as heavy storms fronts from the Continental Equatorial Mass – mEc (ANTUNES, 1980). These concentrated precipitation phenomena cause substantial runoffs, which exacerbates vulnerability to erosion.

The significant erosive potential detected in such researches results mainly due to the deep, sandy soil covering the site whose lack of clay hinders the aggregation of the grains. Steep slopes, torrential rainfalls and fragile vegetation coverage are also significant factors for the erosion potential of Serra Velha.

1.2.3 Vegetation

The entire study area lies on the Savanna (Cerrado) Biome. The savanna vegetation lying on the Urucuia sandstone plateaus is widely used by the agricultural extractivism practiced by traditional, local populations (Carvalho, 2007). In addition, a transitional vegetation develops between the savanna and the deciduous seasonal forest, on the metapelites wavy reliefs. In less agitated relief areas, Veredas are a common occurrence, whether at the top of a plateau or at the bottom of valleys. Aside from the Veredas, the other areas along the watercourses borders sustain a semi-deciduous seasonal forest.

2 METHODOLOGY

Initially, an analysis of the sand mining environmental impacts in the region of Montes Claros is presented. Then, a presentation of the products of the study is made, focusing on GIS techniques and in environmental interpretations. The hypothesis to zone the potential of sand mining on the hillside of the sandstone formations is grounded on the zonings developed by Ribas (1999) and Arioli, et al. (2001). Table 1 summarizes the zoning methodology to detect areas with environmentally vulnerability to mining activities.

We have used ArcGIS 9.3.1 (including extensions ArcHydro and Image Analysis), Envi 4.5 and ERDAS 9.1 to carry out the analysis. The slope map was obtained from the calculation of the derivation moment on a quadratic surface achieved through polynomial regression. To such end, the Envi 4.5 software was fed with data from the Aster GDEM altimetry database.

The Landsat 7 Geocover (2000) was used for visual interpretation, as well as for geometric correction and georeferencing recording. SPOT images and Digital Globe with 2.5-meter resolution were acquired from the Google Satellite Maps Downloader 6.49 and Satellite Image Download 1.2.5.0 Application software. Geological maps at 1:1,000,000 (CPRM / CODEMIG, 2003) and detailed maps at 1:200,000 were used (Soares et al. 2002).

Table 1: Methodology

Phases	Databases
1. Sand mining locations	GESCOM studies (2008), Oliveira Junior (2009) and Souza Júnior *et al.* (2009).
2. Delimitation of the sandstone areas	Geologicalmap (CPRM/CODEMIG, 2003).
3. Hydrogeological inference	Geologicalsurveysfrom CPRM (HEINECK, 1971; COSTA *et al*., 1975; e FEBOLI, 1985). AsterAltimetry GDEM (ERSDAC, 2009). Hydrography (IBGE, 1978)
4. Validation and refinement by remote sensing	Landsat 7 Geocover 2000 (Zulu, NASA) Spot Images (2009) and Digital Globe (10/22/2008)
5. Environmental impact assessment and legal protection based on altimetry, slope, hydrology, and ecosystems.	Above-mentioned databases. Basis of the Vegetation Mapping and Inventory of Native Flora and Reforestation of Minas Gerais 2003-2005 (SCOLFORO & CARVALHO, 2006), updated by researchers of Unimontes in 2009. Vegetation base for Montes Claros (LEITE, 2008).
6. Presentation of the Environmental Zoning as to its vulnerability to sand mining.	

3 DEVELOPMENT

3.1 Characterization of the Environmental Impacts

The sandstone region limits the potential area for slope sand mining. The Urucuia sandstone plays a significant role recharging the hillside springs with water infiltration from flat areas as one easilyrealize examining its hydrogeology. In this sense, Serra Velha stands out as a safekeeping zone, protecting the recharge areas and temporarily avoiding storm flows to reach the main rivers headwaters.

In this respect, it should be noticed how mining activities in slopes pose a significant environmental liability as far silting up springs immediately downstream is concern. Besides that, mining slope cuts where the water appears increases the exudation surface, lowers the water table and already significant torrent flows (Figure 7). It is even noted the interconnection of quickly depletes the porous aquifer. Thus, the water seeping from the slopes during the rainy season would not feed the springs during the next drought season. The geological and hydrogeological studies (ECOPLAN, 2009) of the Rio Verde Grande Watershed Master Plan indicate that the mountains ridge forming the sandstones are significant aquifers feeding the springs that emanate from these basin interfluves.

GESCOM (2008) shows, with details, how the runoff from each Serra Velha sand mines destabilized valleys and thalwegs along ground elevations lower than the ones of the rainwater runoff path creating steep riverbanks and gullies.

In some cases, the mining drainage runs directly to the nearby spring, often burying it. In other cases, the drainage from mining works flows downwards increasing the connected ravines erosion before reaching a watercourse, which will then receive all accumulated sediment load. Figures 4 to 6 photographs show the extent of such environmental impacts.

Also, it is not uncommon to join the drainage of mines with the drainage of roads, adding these two drains from various mines using the roads.A sub-basin analysis should use an integrated approach to evaluate how alterations in land use provoking erosion and silting, such as mining, roads and other projects, will affect the surface drainage.

3.2 Zoning of the environmental vulnerability to sand mining

Based on the technical background provided by Pereira (1984), Araújo et al. (1995) and Leite (2008), as well as on the mapping products from this work, it became possible to present a preliminary mapping of key areas as to the vulnerability to the erosion of slopes affected by mining and the resultant watercourses siltation.

Figure 4: Destabilization of slopes downstream of the sandpit SóbritaMineração, in Serra Velha. The gully formed drains the sediment inflow into the Tigre River. Geographic coordinates UTM 23S 0621702/8125467 (43 ° 51'27 "W/16 ° 57'6" S).
Source: SOUZA JÚNIOR et al. 2009, p. 7.

Figure 5: Sandpit Areeira Adauto Furtado Veloso, in Serra Velha. It should be noticed that the sand drains directly to the road increasing its drainage flow. Geographic coordinates UTM 0618332/8125637 23S (43º53'21"W/16º57'1"S).
Source: SOUZA JÚNIOR et al. 2009, p. 6.

Primary databases were consulted to preparealtimetry maps, contour levels, elevation and inclination digital model of the Urucuia sandstone region, and detailed maps for Serra Velha. A preliminary notion about the regional relief was achieved from the combined assessment of such maps.

Figure 6: GuavinipãRiver bed silting (Serra Velha) showing cattle footsteps and lack of riparian vegetation.
Source: GESCOM, 2008, p. 78.

Pereira's concept of fronts of instability (1984) was precisely achieved when the slope map and the altimetry map were examined all together. These would be the areas with more natural regional instability – and any anthropogenic changes may break the fragile balance of these slopes.

The overlap of instability fronts, altimetry and geological mapping shows that the outskirts of instability fronts do not exhibit a direct interface with the outcrops of Urucuia sandstone in most elevations of the residual plateau. The largest elevation gaps, most of the times, are closer to the thalweg in valleys of river dissecting – however, even in such cases, the erosive imbalance in the vicinity of the thalweg due to excessive drainage has a headward effect on the equilibrium profile all over the dissecting slope. This contributes to increase the triggering of gullies as characterized by Pereira (1984) and GESCOM (2008), as shown on Figure 7.

In some cases, (at the eastern boundary of the sandstone plateau), the plateau fronts are covered with debris-lateritic surfaces and ferruginous concretions, more resistant to erosion. These concretions provide greater stability to the slopes, working as cornices (vertical profile) and even as geomorphic thresholds (horizontalprofile), in such way that they have protected the São Francisco plateau from its razing over the geomorphological time.

Thus, sub-basins draining into fronts of instability running directly over the Urucuia sandstone were zoned as critical areas. Therefore, remain into account the GESCOM directive of 2008 and item III of Art. 7 of CONAMA resolution 369 of 2006 which recommend considering the watershed when analyzing the environmental impact of mining activities. It should be stressed that sand mining in slopes at instability front areas is tempting under an economic point of view, despite being extremely vulnerable in terms of environment, both in the short as in the long term.

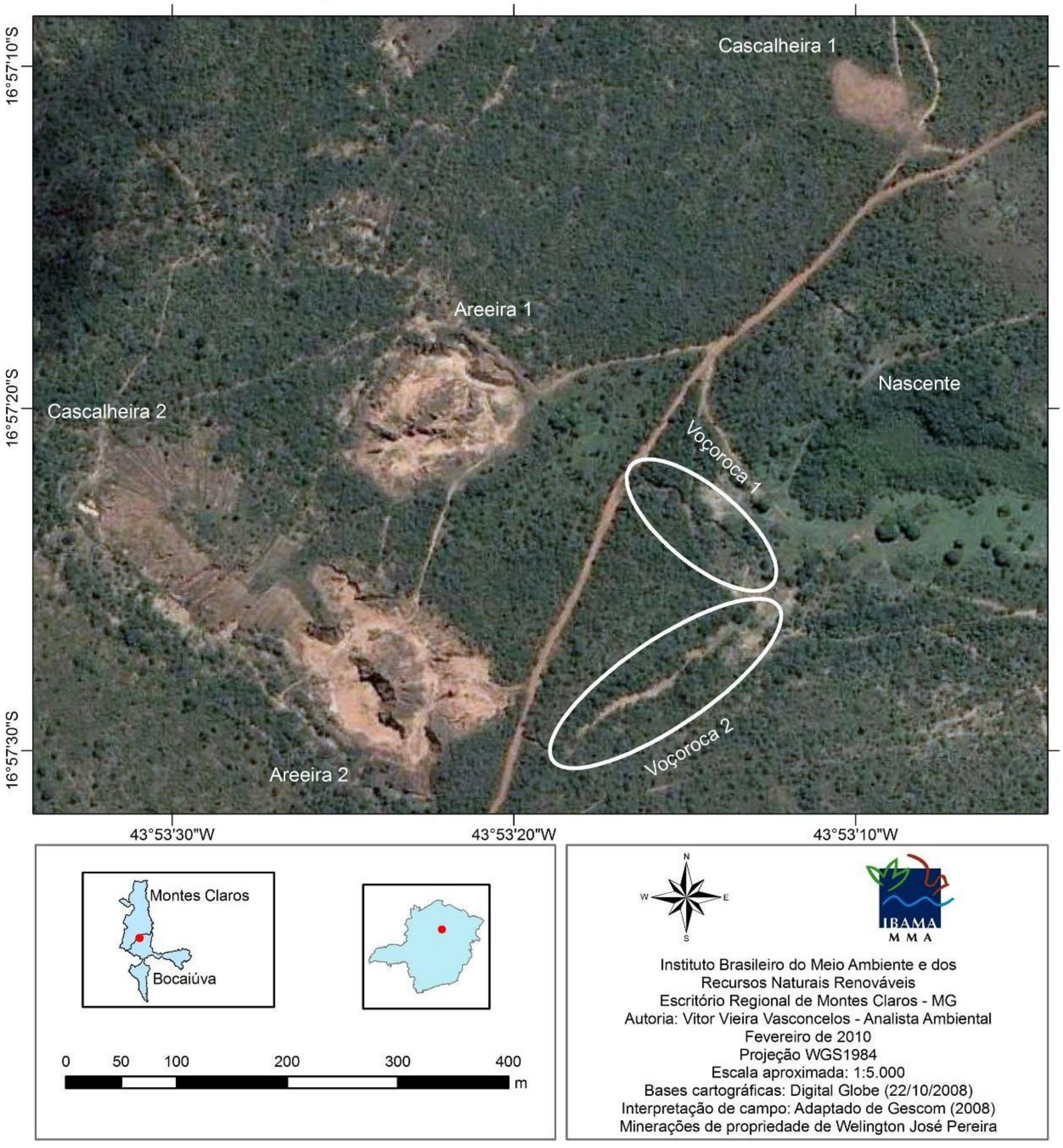

Figure 7: Illustrative map showing the synergistic impact of the drainage from sand mines, gravel extraction and roads in Serra Velha region.

Areas from Urucuia sandstone draining to ecosystems in which the dissection of the relief is dominated by the formation of Veredas have also been zoned as vulnerable.To accomplish this, we have performed a combination of the geological mapping (CPRM / CODEMIG, 2003 and Soares et al. 2002) with the bases of vegetation mapping and inventory of the Native Flora and Reforestation of Minas Gerais from 2003 to 2005 (CARVALHO & SCOLFORO, 2006), updated by the researchers team of Unimontes in 2009.Such areas are environmentally sensitive from an erosion point of view due to the rich although fragile ecosystem ecology of the Veredas.

The delimitation of areas with environmental vulnerability and crucial environmental vulnerability as well were refined based on the mapping of the areas of exposed soil by Leite (2008) and on the analysis of satellite images. This was how the delimitation of the watersheds draining into the stains with predominance of exposed soil was made.

The significant synergistic environmental impact of the exposed soil areas in Serra Velha has already been detailed (GESCOM program, 2008) as previously commented in 'Characterization of the Environmental Impacts'. Watersheds draining into areas where the predominant profile varies from rolling to strongly rolling (over 20), were also ranked as areas of crucial vulnerability. As directed by Leite (2008) these are fragile areas to face erosion and strong erosion processes in the municipality of Montes Claros. Drainage areas in Serra Velhawith both, predominance of exposed soil and profile varying from rolling, to strongly rolling (greater than 20^{o}) were classified as extremely vulnerable. It should be emphasized that all sandpits recognized as such in Serra Velha are located in either crucially or highly vulnerable areas.

Maps in Figures 8 (regional view) and 9 (Serra Velha) show the results of the zoning process. Zoning was based on the information available in existent studies and was accomplished within the schedule proposed by the Regional Collegiate Unit (URC) of North COPAM of Minas Gerais. This zoning can be improved in the future, especially with the implementation of urban master plans which include specific territorial tools regarding mining aimed at construction works, as specified in § 4, Art. 7th CONAMA Resolution 369, of 2006.

4 CONCLUSIONS

Serra Velha sand mining has caused severe environmental impacts, as shown in GESCOM (2008), Leite (2008), Almeida & Pereira (2009), Souza Jr. et al. (2009) and Oliveira Junior (2009). The more significant impacts are due to erosion and silting of watercourses. However, the environmental agencies have encountered difficulties in managing the environmental licensing and enforcement related to such projects.

The proposed zoning work in this paper helps the performance of a spatial assessment of this environmental impact. The proposed areas for environmental zoning (Figures 8 and 9) have varying environmental vulnerability to sand mining. All sandpits recognized as such in Serra Velha are located in either crucially or extremely vulnerable areas.

The licensing agencies SUPRAN or COPAM analyze projects in a case by case basis and have the prerogative to require environmental licenses to any undertaking having significant potential for environmental degradation even when a preliminary AAF (Environmental Authorization toOperate)was previously granted , according with § 4 of Article 2 of COPAN 74 Resolution of 2004, and Art. 6 of the State Decree 44,844 of 2008.

Supported by the technical considerations submitted by this study, the Regional Collegiate Unit of North of Minas Gerais, of the State Environmental Policy Council of Minas Gerais, decided on March 17, 2010, that all mining activities in Serra Velha mining should apply for a Class 3 license pursuant to COPAM Resolution 74 of 2004. Therefore, any undertaking without an

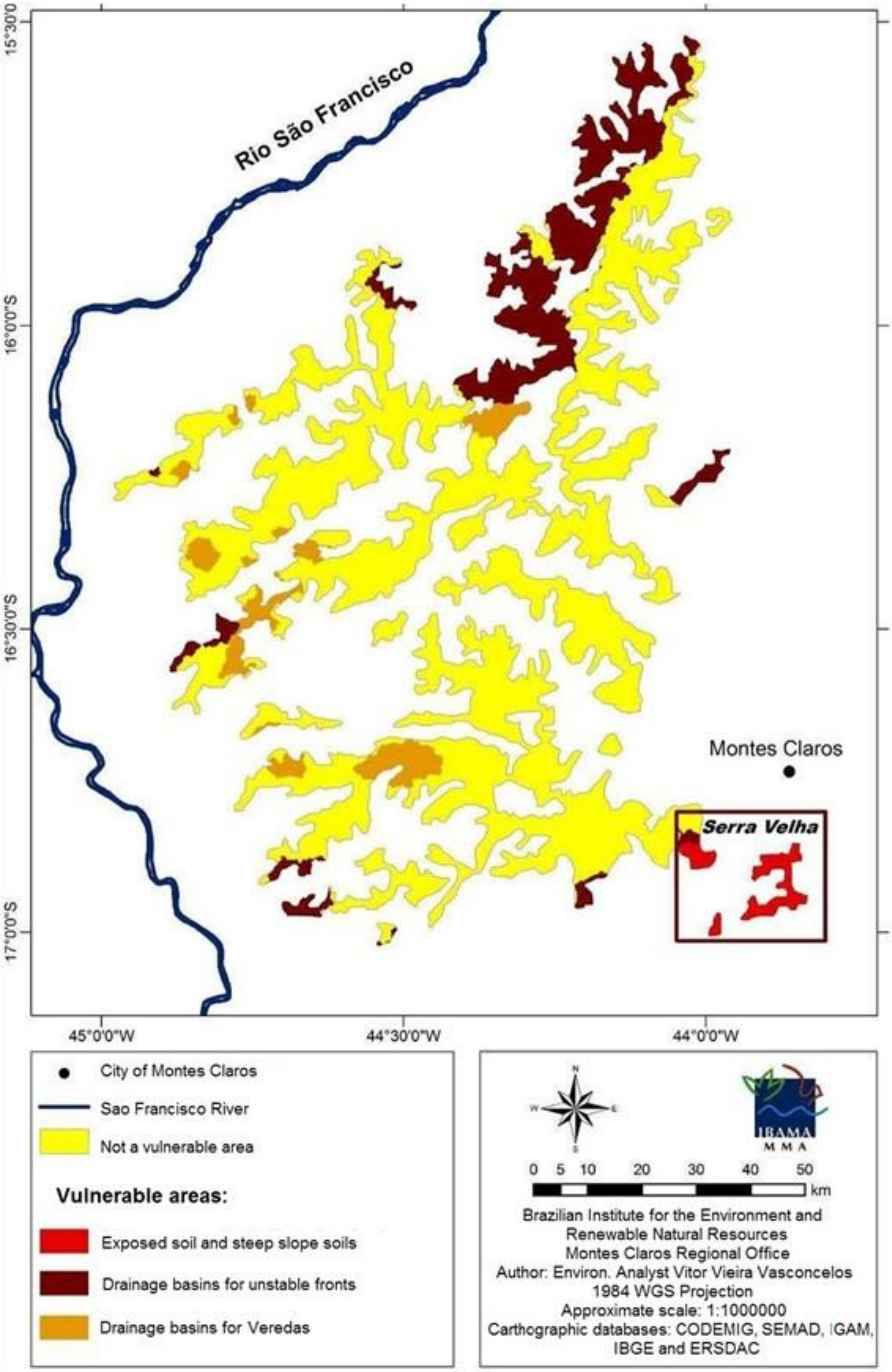

Figure 8: Environmental Zoning for sand mining in slopes – Urucuia sandstone sedimentary plateau.

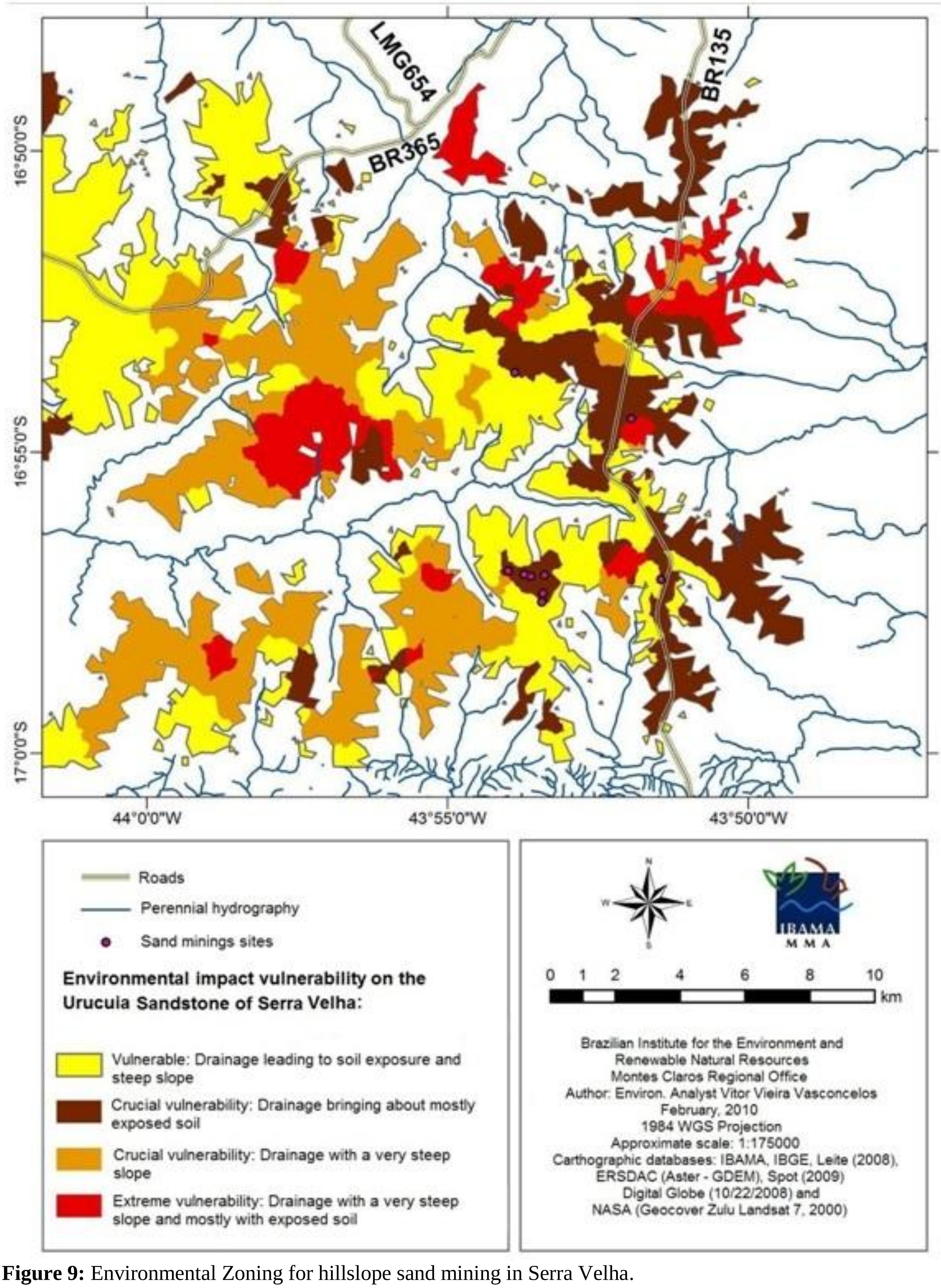

Figure 9: Environmental Zoning for hillslope sand mining in Serra Velha.

AAF should apply as well for anenvironmental license Class 3 from the Regional Collegiate Unit (URC) of North COPAM of Minas Gerais. Consequently, any undertaking with a valid AAF should apply for an environmental license Class 3 at the time of its renewal. The polygon shown in Figure 2 encloses the area whose sand mines should apply for a licensing; it was set based on the mapping of the potential areas for sand mining outlined in this paper.

A suggestion to change the directive for environmental licensing of sand mines (Table 2) is also proposed; it may be forwarded through URC to COPAM's general meeting. Table 2 can also be used for other types of mining undertakings and may be applied in other regions, as well. However, Table 2 must always be tied up to some specific environmental zoning for sand mining undertaking.

Table 2: Proposed changes for the licensing of mining projects

Location	**Minimum requirement (Environmental Permit to Operate [AAF] or Environmental Licensing)**
Vulnerable area identified through environmental zoning	Environmental licensing
Permanent Protection Area (APP)	Environmental licensing + Studies required according to Art. 7th of CONAMA Resolution 369, of 2006.
Other areas	Environmental Authorization to Operate (AAF)

Note: *The expression "vulnerable area identified through Environmental Zoning" means an environmental zoning specifically including the mining environmental vulnerability. This kind of vulnerability may be approached in Ecological-Economic Zoning, Urban Master Plans, Watershed Master Plans, Management Plans of Conservation Units, among others studies*.

The legal protection of Serra Velha and other fronts of the Urucuia sandstone plateau would be quite enhanced by the creation of an Environmental Protection Area – APA – for the region. The scenic beauty of these mountains, the fragility of its slopes, the existence of extractive local communities and the anthropic pressure caused by the development of Montes Claros, are powerful arguments favoring the option for an APA. The implementation of this conservation unit of sustainable use would bring about new options for regional planning of the region. In particular, the establishment of an APA's advisory board uniting residents and entrepreneurs would constitute a new instrument for resolving conflicts and for proposing new standards of land use. As a result of the APA creation, the development of its Management Plan would pose a fortuitous opportunity for the improvement of the current zoning through multidisciplinary team activities and all necessary social participation. Nevertheless, the balance of the represented powers and the opening of a dialogue between social and economic groups act as supporting columns, so that neither the environmental nor the restrictions on production activities will pose obstacles to sustainable socioeconomic development of the region.

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