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GEOMORPHOLOGICAL INDEX AS SUPPORT TO URBAN PLANNING

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Abstract

Growth without adequate city planning can lead to potential risk areas for growth and accelerated erosion, which is present in considerable portions of urban areas of the underdeveloped and developing world. The clue to an environmental issue is not a conscious and complete task in territorial planning. In this sense, it is fundamental to apply the potential of land use and occupation, in order to prevent and mitigate the environmental problems of disorderly or inadequate occupation of land. The use of geomorphology as a basis for the analysis of metropolitans is in the stage of the planning of the planning of metropolitan building, by the date of the planning of the cities of the underground process by the county passes, to become a tool of importance fundamental for the establishment of action plans. The work is the first plan to choose environmental guidelines, there is no sense to guide and subsidize the development of plans and directors. For this, we use the Geomorphological Index as a subsidy to the urban occupation planning of areas of occupation in the municipality of Itabirito, Minas Gerais.

Keywords: Geomorphology; territorial planning; environmental analysis.

Resumo / Resumen

ÍNDICE GEOMORFOLÓGICO COMO SUBSÍDIO AO PLANEJAMENTO URBANO

O crescimento sem planejamento adequado das cidades pode acarretar em áreas potencialmente de risco a movimentos de massa e erosão acelerada, o que se mostra presente em porções consideráveis de áreas urbanas do mundo subdesenvolvido e em desenvolvimento. É indício de que a questão ambiental não recebe a devida atenção nos vários tipos de planejamentos territoriais. Nesse sentido, é fundamental que o planejamento do território das cidades contenha elementos analíticos que induzam e facilitem a avaliação do potencial de uso e ocupação da terra, de maneira a prevenir e mitigar os problemas ambientais decorrentes da ocupação desordenada ou inadequada da terra. A utilização da geomorfologia como base da análise integrada do meio ambiente pode ser usada não apenas na etapa de planejamento das cidades, como também da sua gestão, uma vez que as dinâmicas da superfície e subsuperfície constituem o fundamento das transformações pelas quais o município passa, tornando-se uma ferramenta de fundamental importância para o estabelecimento de planos de ação envolvendo o desenvolvimento sustentável dessas áreas. O objetivo do presente trabalho é o de apresentar abordagens complementares das análises ambientais, no sentido de orientar e subsidiar o desenvolvimento de Planos Diretores e de outros instrumentos de planejamento territorial. Para isto, utilizamos o Índice Geomorfológico como subsídio ao planejamento urbano na indicação de áreas potenciais para ocupação no município de Itabirito, Minas Gerais.

Palavras-chave: Geomorfologia; planejamento territorial; análise ambiental.

ÍNDICE GEOMORFOLÓGICO COMO SUBSIDIO A LA PLANIFICACIÓN URBANA

El crecimiento sin planificación adecuada de las ciudades puede acarrear en áreas potencialmente de riesgo a movimientos de masa y erosión acelerada, lo que se muestra presente en porciones considerables de áreas urbanas del mundo subdesarrollado y en desarrollo. Es indicio de que la cuestión ambiental no recibe la debida atención en los diversos tipos de planificaciones territoriales. En este sentido, es fundamental que la planificación del territorio de las ciudades contenga elementos analíticos que induzcan y faciliten la evaluación del potencial de uso y ocupación de la tierra, de manera a prevenir y mitigar los problemas ambientales derivados de la ocupación desordenada o inadecuada de la tierra. La utilización de la geomorfología como base del análisis integrado del medio ambiente puede ser usada no sólo en la etapa de planificación de las ciudades, sino también de su gestión, ya que las dinámicas de la superficie y subsuperficie constituyen el fundamento de las transformaciones por las que el municipio pasa, convirtiéndose en una herramienta de fundamental importancia para el establecimiento de planes de acción que involucren el desarrollo sostenible de esas áreas. El objetivo del presente trabajo es el de presentar enfoques complementarios de los análisis ambientales, en el sentido de orientar y subsidiar el desarrollo de Planes Directores y de otros instrumentos de planificación territorial. Para ello, utilizamos el Índice Geomorfológico como subsidio a la planificación urbana en la indicación de áreas potenciales para ocupación en el municipio de Itabirito, Minas Gerais.

Palabras-clave: Geomorfología, planificación territorial, análisis ambiental.

INTRODUCTION

According to Bathrellos (2007), approximately 70% of the world's population currently lives in cities. Due to its intensity, the urbanization process around the world has brought environmental impacts affecting not only natural ecosystems, but also the human population, even though the degree, extent and diversity of these impacts are different depending on regions and countries (BATHRELLOS, 2007). They are partly caused by the disappearance of vegetation cover and increasing waterproof of the land surface with effects on the frequency and intensity of flooding in urban centers (COOKE & DOORNKAMP, 1974; HUDSON, et al., 2015). Likewise, cities cut off by waterways, including those of small and medium size, are subject to periodic flooding, leading to the loss of material possessions and human lives (WOLMAN & SCHICK, 1967; MONTGOMERY, et al., 1995; SKILODIMOU, et al., 2003; TOMINAGA, et al., 2009). River flooding and inundation due to strong rain events are caused by low infiltration rates due to the intensification of waterproofing by buildings and constructions causing significant economic losses in urban areas, especially in tropical humid zones (THORNE et al., 1997; GUPTA, 1999). No less important are the frequent landslides recorded in urban areas, even in those considered stable from a tectonic point of view (GABET, 2007; GLADE & CROZIER, 2010; GIORDAN, et al., 2010). Besides compromising the balance of the ecosystems, anthropic actions, enhanced by population densification in places that are often unsuitable for buildings and constructions, cause accelerated erosion processes to increase, especially in the periphery of large cities, impacting not only the people, but also infrastructures of water collection and watercourses, contributing also to siltation (SALA & INBAR, 1992; COOKE, 1976; MARANI, et al., 2001; URBAN, 2002; CLARKE, et al., 2003; THORNBUSH, 2015).

Land occupation in areas potentially at risk of mass movements and accelerated erosion in considerable portions of urban areas of the underdeveloped and developing world, indicates that the environmental issue does not receive due attention in various types of territorial planning (ALEXANDER, 1991; (GUPTA & AHMAD, 1999; ANTONY, et al., 2001; BOCCO, et al., 2001; SKILODIMOU, et al., 2003; FOOKES, et al., 2005; PARO & SMITH, 2008; GLADE & CROZIER, 2010; MONTZ & TOBIN, 2011; CASAGRANDE, et al., 2017). That is also the case of the use of river systems for effluent emission, with rivers losing the ability to maintain aquatic ecosystems, with real negative impact on people's quality of life and increasingly difficulties in the catchment of permanent rivers for drinking water. Therefore, the urbanization process is one of the most active factors in the transformation of cities and their surroundings (SALA & INBAR, 1992; URBAN, 2002).

In Brazil, this process began at the turn of the nineteenth to the twentieth century, when it ceased to be a monarchy and became a republic. According to Nascimento, et al. (2013), this period was characterized by significant political, economic and social changes, such as the end of slavery in 1888, the year in which the modes of production were modified, leading to the immigration of populational contingents of European origin, and to a lesser extent, Asian populations. This contingent of immigrants came to replace the slave labor, but gradually, part of them chose to replace the countryside with the cities, participating in the process of industrialization and urbanization of the country.

Reis (1995, apud NASCIMENTO et al., 2013) draws attention to the fact that the fall of the monarchy, promoted by the military coup d'état in 1889, was supported by the republican movement. This had a civil base, consisting of the progressive elite, which attributed economic and social backwardness to the monarchy, thus blaming it for the country's lack of development. The republican political project intended to create conditions for capitalist development based on the European model, whose modernization had positivist pillars, and it was supported by the military and an incipient urban bourgeoisie, composed of liberal professionals and independent farmers that arose from slave labor. One of the political changes that took place in this process was the transformation of the former provinces of the Empire into member states of a federation, the United States of Brazil, and these states began to create means for political control and control of the management of their respective territories (NASCIMENTO et al., 2013).

In the early twentieth century, Brasil República, which had a strong positivist base in its ideological pillars, sought to transform itself into a modern and urban country, even though it was characterized as a basically agricultural one. It aimed to initiate a new era of progress, industrialization, urbanization, and increased rationality in political and administrative decisions, and these yearnings would materialize in cities. They were to be the scene of this modernization (NASCIMENTO et al., 2013). However, only in the mid-twentieth century did Brazil cease to be predominantly rural and become urban.

According to Holanda (2010), in 1940 the urban population was 26.35%, jumping to 44.67% in 1960 and reaching, in 1970, the rate of 55.92%. In the 1980s urbanization reached 67.59%, increasing to 78.36% by 1996 and recording 84.72% in 2015 according to data from IBGE. The strong process of urbanization in Brazil has generated the phenomenon of metropolization, with the development of large metropolitan centers, including the Metropolitan Region of Belo Horizonte - RMBH.

The RMBH was created in 1973 by Federal Complementary Law No. 14/73 and is currently regulated by complementary laws of the State of Minas Gerais (Law No. 88/2006 and Law No. 89/2006). The city of Itabirito, despite its proximity to the capital, is not part of RMBH, but is part of the Metropolitan Necklace, formed by municipalities around RMBH affected by the metropolization process, which seeks to integrate the planning, organization and execution of functions of common interest. Not being part of the RMBH itself, Itabirito is not part of metropolitan planning. However, other planning instruments are used, such as the Master Plan, regulated by the Federal Constitution of 1988 and the Cities Statute (Federal Law 10.257 / 2001), which determine that municipalities with a population larger than 20.000, as is the case of Itabirito city, Minas Gerais State, Brazil, are to adopt this instrument as a guide for urban planning.

However, after seventeen years of implementation of the legal bases of one of these instruments, it is necessary to raise questions regarding the Master Plan of the municipality. One of the most important is the question of how to propose and conduct public policies in the environmental sphere, taking the municipality as bio-physical unity, since the organization and structuring of natural elements do not tend to obey the political-administrative spatial limits adopted as the basis of planning in the country. Moreover, how urban-environmental aspects are addressed, and whether they are really effective is also a pertinent issue. Recurrent environmental problems reported on urban areas indicate that there is the non-observance, or secondary attention, of the natural elements in the plans aimed at directing urban occupation, although as concept these elements are considered a sine qua non condition for the balanced development of cities.

Taking these issues into account, it is essential that planning of city territory contains analytical elements that induce and facilitate the assessment of potential land use and occupation in order to prevent and mitigate environmental problems arising from disorderly or inappropriate land occupation (COATES, 1976; COOKE, 1976; SEAR, et al., 1995; BATHRELLOS, 2007; ADELI & KHORSHIDDOUST, 2011; HUDSON, et al., 2015).

The natural landforms or even those created or induced by human activity constitute elements of the Earth surface that integrate in themselves factors and characteristics related to their genesis and dynamics (AUGUSTIN, 1979). It can be assumed that they constitutes the synthesis of the action of climatic factors and flora and fauna on the rocks, having water and other agents as instruments (KIRKBY, 1978; THORNE et al., 1997; SOULSBY et al., 2006). More recently, in view of the scale, scope, frequency and intensity of its actions, man has also entered this equation, accounting for the changes in the dynamics of the earth's surface, which involves the action of erosion processes including mass movements and siltation, leading to the loss of natural resources fundamental to guaranteeing quality of life for its residents (COOKE, 1976; BATHRELLOS, 2007; MARANI, 2001). Geomorphology takes relief forms as its object of study in all its different dimensions, from genesis to its dynamics and evolution. It provides, therefore, a consistent theoretical and methodological basis for the analysis of the environment since they constitute a more or less permanent structures of the natural landscape that merge in itselfe similar characteristics in terms of geological variability, slope geo-covers, vegetal coverage, and surface and subsurface processes, including river and groundwater levels (COOKE & DOORNKAMP, 1974; BROWN, 1996), as well as water resources, enabling to detect various dimensions of environmental changes in urban space. Thus, analysis of the landforms, its components and dynamics, enables evaluation of the potential use of the various land domains that make up a region.

In fact the use of geomorphology as a basis for integrated environmental analysis can be used not only in the planning stage of cities, but also in their management, since surface and subsurface dynamics are the venue where the transformations the municipality undergoes. This makes it a fundamentally important tool for establishing plans of action involving the sustainable development of these areas (DOUGLAS, 1988; GUPTA & AHMAD, 1999; ANTHONY, 2001; WILCOCK, et al., 2003; BOHNET, 2010; MOHAPATRA, 2014; HUDSON, 2015).

The aim of this paper is to present complementary approaches to environmental analysis, in order to guide and support the development of Master Plans and other territorial planning instruments. For this, we proposed a Geomorphological Index as an aid to urban planning in the indication of potential areas for occupation in the municipality of Itabirito, Minas Gerais.

GENERAL CHARACTERISTICS AND ENVIRONMENTAL PROBLEMS OF THE STUDY AREA

The municipality of Itabirito (Figure 1) is located in the Metropolitan Mesoregion of Belo Horizonte, the capital of the State of Minas Gerais, Brazil, integrating, along with three other municipalities (Mariana, Diogo de Vasconcelos and Ouro Preto) the Ouro Preto Microregion. It is composed of the district headquarters (formerly Nossa Senhora da Boa Viagem Village of Itabira do Rio de Janeiro, and after 1745, Parish of Itabira do Campo), Acuruí (formerly the Parish of Rio de Pedras), São Gonçalo do Bação and São Gonçalo do Monte (MOURA 2007). It has a population of 45,449 people according to the IBGE 2010 census. As part of the mineral province called Quadrilátero Ferrífero (QF), Itabirito has historically had mining activity as one of the engines of its economy. From the twentieth century onwards, this activity has grown throughout the region, presenting large exploration areas and their caves, and considerable areas of sterile waste. This process entails, among many other impacts, the siltation of watercourses, generating all the environmental changes that result from it and which, secondarily, but no less importantly, affect the availability of water resources. Part of these impacts results from the lack of management in controlling the dynamics of occupation, which leads to problems of disorderly expansion, an increase in areas of risk, compromised environmental protection areas and inadequate use of natural resources.

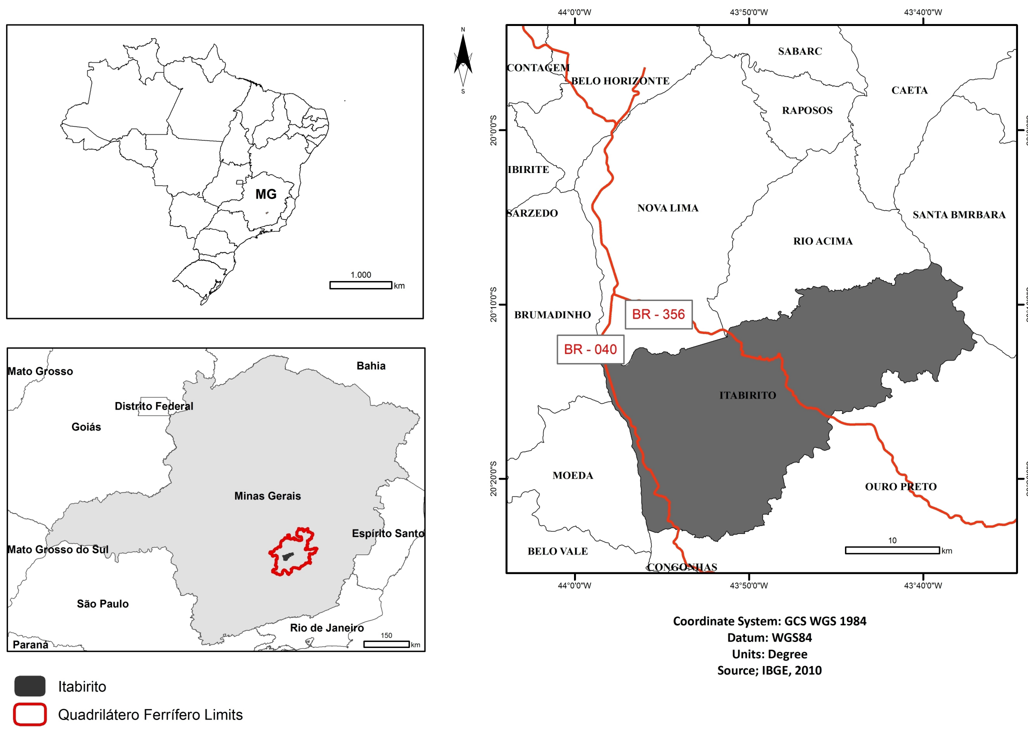

Figure 1 - Location map of the municipality of Itabirito - MG – Brazil (Source IBGE, 2010)

GEOMORPHOLOGICAL AND GEOLOGICAL CONTEXT OF ITABIRITO

The QF occupies an area of approximately 7,000 km², forming one of the most important orographic sets in the state of Minas Gerais. Altitudes vary between 800 and 900 meters on average, and most have ridges lines exceeding an elevation of 1,200 meters. It is formed by a complex folded chain, in which the layers of quartzites and itabirites form a system of ridges located at higher altimetric levels in relation to the alveolar depressions, open in granites, shales, phyllites and gneisses.

According to Hader & Clamberlim (1915), the QF relief is the result of its structure, coupled with the differential erosion in which quartzites and itabirites form the substrate of the highlands, while schist-phyllites constitute the substrate of the medium ones and gneiss granites the lowlands. The highest portions constitute a set of raised ridges and erosive surfaces that have a shape close to a quadrangle, surrounding the lands of lower altitudes where the Rio das Velhas River runs, forming the base level of the central portion of the QF.

The QF was classified by Varajão (1991) as a mosaic containing six geomorphological provinces, namely: Serra do Caraça, Sinclinal Moeda, Serra de Ouro Branco, Serra do Curral, Bação Complex and Sinclinal Gandarela. The highest altitudes of the QF are found in Serra do Caraça, reaching 2,000 meters. According to the same author, the QF landscape has strong traces of differential erosion, present in small erosion surfaces, with evident litho-structural control. Diffuse and concentrated flow processes, leading to furrows and ravines, and occasional mass movements occur in areas that have undergone anthropic intervention. Schists and micaschists are rocks that are vulnerable to weathering, forming an impermeable clay layer, which favors intense runoff in areas with less dense vegetation.

METHODOLOGY

For the elaboration the Map of the Geomorphological Index of Land Use and Occupation Potential (Figure 7), which aims to assist in planning for the occupation of new areas, the following elements were considered: Geology-Geotechnics, Hack Index (HI), Roughness Concentration Index (RCI) and Accelerated Erosive Processes (gullying) and Geomorphological Units, according to the following steps:

a) Elaboration of the Geological and Geotechnical Map (Figure 2), in which the classification of the legend components has values related to the lithology / resistance aspect of the rocks with grades from 0 to 10 (table 1), in which the highest grade has, according to Parizzi (2011), the greatest potential in terms of susceptibility to weathering / erosion / mass movements.

Lithological units	
Legends components	Grades
Laterites	2,0
Dolomite	4,0
Phyllite, dolomite	5,0
Phyllite	5,5
Metarenite	6,0
Itabirite	7,0
Granite	8,0

Table1 - Notes concerning lithological units / weathering resistance / erosion / gravitational transfer. (Source: PARIZZI, et al. 2011).

b) Map of the Roughness Concentration Index (RCI), following the methodology proposed by Sampaio & Augustin (2014), as shown in Figure 3. The use of the RCI aims to “quantify and classify the landform units based on spatial distribution of their gradient through compartmentalization and quantification from the analysis of spatial pattern distribution of the landform declivity (using indirect measurements of hillslope inclination and length), and considering their values in three-dimensional space and not in two-dimensional as in the case of analysis via profiles” (SAMPAIO & AUGUSTIN, 2014, p. 52). We considered the same ranges for relief units used by the above authors, namely: flat - RCI values below 2.5; gently undulating - RCI values from 2.5 to 6; undulating - RCI values from 6 to 14; strongly undulating - RCI values from 14 to 30; hilly - RCI values from 30 to 45; strongly hilly- RCI values above 45.

c) Hack Index Map, calculated from index values, which is a quantitative parameter since it is related to the power of the water / river flow to carry material of a given size (flow competence) and the characteristics of the channel. According to Fonseca and Augustin (2011), this index was proposed by Hack (1957a, p. 87-90) based on "empirical evidence" during his studies on the Potomac River basin (USA), in which he "observed that the value of the product slope of the channel (S) by its length (L), is directly related to the competence of the river." This relationship is represented according to Hack (1957, apud FONSECA & AUGUSTIN, 2011) by $S=25/M^{0,6} * L$ where "M represents the mean diameter of the riverbed particles", there being a functional relationship between these variables, whereby there is a corresponding increase in the diameter of the particles deposited in the river in relation to increases in the SL value.

For the elaboration of the index, we used: a) Knickpoint Finder tools developed by Salamuni, et al. (2013), which coupled with Arcgis software, seek points that signal ruptures in the ground, and was therefore used in the search for relief anomalies with drainage inferences; b) the River Merge algorithm also developed by Salamuni, et al. (2013) to unify drainage segments; c) Arcgis software for Knickpoint Finder's information unification system and operating platform; d) NASA Shuttle Radar Topography Mission (SRTM) images, which were processed by interpolation through the cubic convolution method by the Topodata project with spatial resolution of 30 meters.

d) Map of the Accelerated Erosion Process (gullying): consists on the Identification of accelerated erosive processes (gullying) by satellite imagery and their vectorization on geoprocessing software (Figure 5). To identify occurrences of erosive processes we used the Google Earth software (2018) and obtained the data related to this variable by manual vectorization.

e) Map of Geomorphological Units of the Municipality of Itabirito at a scale of 1: 50.000 (Figure 7), elaborated from relief interpretation, having as a support instrument: a) the hypsometry; b) slope; and c) analysis of longitudinal profiles that enabled the identification of five large structures of the physical landscape of the study area. These were used as a basis for the elaboration of the Map of the Geomorphological Index of Land Use and Occupation Potential. The classification of the map legend was performed by obtaining the corresponding weights of the components of the Geomorphological Units in view of land use and occupation (Table 2). The legend shows weights that correspond to the classification of the components with values from 0 to 10 where the higher the grade, the greater the potential use of the respective unit. The Delphi method was used for the composition of the notes. According to Moura (2007), it consists of obtaining the weights based on the choice of a multidisciplinary group of specialists, who know the phenomenon well, as well as knowing the spatial reality where it is located. These specialists are asked to rank or place the variables in order of importance for the manifestation or occurrence of the studied phenomenon. In this case, the answers of 17 experts were obtained for the calibration of the values of the notes, presented in the table below, that is, with the notes referring to the legend components of the geomorphological map:

Geomorphological Units	
Legend components	Grades
Lowered Dissected Surface	8
Dissected Residual Level	6
Filled Fluvial Valley	4
Flat Top of the Intermediate Level	3
Elevated Residual Surface	1

Table 2 - Notes referring to the Geomorphological Units of the municipality of Itabirito – MG

f) Map of the Geomorphological Index of Land Use and Occupation Potential in the Municipality of Itabirito (Figure 9) results from the classification and weighting of all five variables listed above (Geology-Geotechnical Relief Units Index, Roughness Concentration Index, Hack Index and Accelerated Erosion Process (gullying) for their integration through the Multicriteria analysis method.

Proposed as a basis to assist in territorial ordering, it takes into consideration the integration of the other variables that are intrinsically associated with each other, and reflect the spatial organization of the area. The Map was elaborated from the classification and weighting of the five variables, as shown in Table 3.

The procedure is based on mapping the variables by information plans and defining the degree of relevance of each one as well as its legend components, and the mathematics used is the Weighted Average (MOURA, 2007). The use of Weighted Average creates an ordinal classificatory space, which can also be understood as an interval scale. This process can also be used on a nominal scale, as long as events are ranked according to some value criteria. The weighting was performed by "knowledge driven evaluation", and the composition of the weights of each variable also performed by the Delphi Method. After weighting, the variables were normalized in numerical ranges from 0 to 1. The lowest values are associated with low potential and the highest values with high potential for land use and occupation, as shown in table 3 below:

Geomorphological Index of Land Use and Occupation Potential	
Variables	Grades
Geomorphology	35%
Roughness Index	25%
Hack Index	17%
Geology	13%
Gull density	10%

Table 3 - Weights of the variables that compose the Geomorphological Index of Land Use and Occupation Potential of the municipality of Itabirito

In the establishment of weights for Multicriteria Analysis, the geomorphology variable received the highest weight of 35%, since it is assumed that the relief constitute an integrated feature of the environment responding to the various factors and variables involved in the Earth's surface dynamics, being affected and affecting all the elements that make up the landscape, including anthropic elements (COOKE & DOORNKAMP, 1974; VERSTAPPEN, 1983; GUPTA & AHMAD, 1999; BOCCO, et al., 2001; BARTHELOS, 2007).

RESULTS

The variables used to obtain the Map of Geomorphological Index of Land Use and Occupation Potential of the municipality of Itabirito (Geomorphological Units, Geology-Geotechnics, Hack Index, Roughness Concentration Index, and Gully Accelerated Erosive Processes) express characteristics related to the elaboration of the relief as the expression of altitude, slope gradient and length, and of form, while at the same time reflecting the relationship that exist between these different elements (modified from Hypergéo, 2018), their main properties and potential for use in the study area, as can be seen in the synthesis table (Table 4).

Geomorphological Units	Physical Environment Variables			
	Geology	Roughness Index	Hack Index	Gullies
Elevated Residual Surface	Itabirite, phyllite	Heavily steep	Very high	Low
Flat Top of the Intermediate Level	Rust Quartzite, phyllite, dolomite	Wavy to strongly wavy	Very low to low	High
Dissected Residual Level	Metarenite, phyllite dolomite, granite	Heavily wavy to steep	High to very high	Very high
Lowered Dissected Surface	Phyllite/dolomite; granite, metarenite, quartzite	Heavily wavy	Medium to high	High
Filled Fluvial Valley	Granite/Metarenite	Wavy	Very low to low	Medium

Table 4 - Summary of characteristics of the physical environment by geomorphological unit of the municipality of Itabirito

The results of the Mapping of Geological-Geotechnical Units of the Municipality of Itabirito (Figure 2) are important indicators of the conditions for occupation of the area by constructions and civil construction works. They are also reflected in the Map of Geomorphological Units (Figure 7), as they indicate the susceptibility of rocks to processes of relief elaboration, although other factors are also associated with the evolution of the landscape, making it so there is no real overlap between geology and forms of landscape.

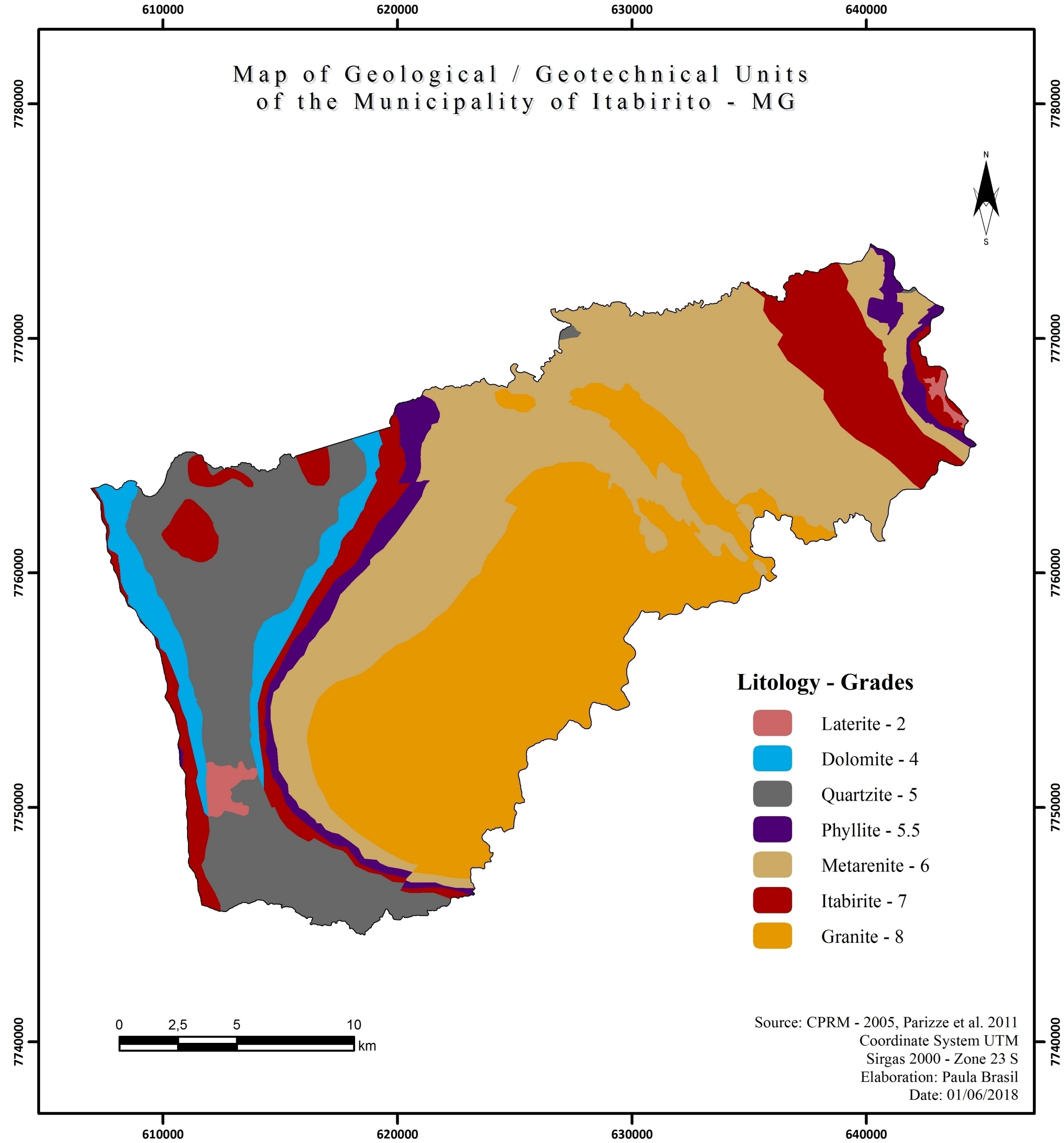

Figure 2 - Map of Geological / Geotechnical Units of the Municipality of Itabirito

The Geological-Geotechnical Map of the Itabirito municipality indicates, according to the Parizzi et al. (2011) classification used in the legend, the predominance of crystalline granite rocks in the central, topographically lower portions of the municipality. These rocks, when subjected to humid climatic conditions with high temperatures, undergo intense chemical and mechanical weathering, leading to the formation of thick geocouplings that favor the action of erosive processes and mass movements, especially on steep slopes, without, or with little vegetation cover (YOUNG, 1972; OLIVA, et al., 2003; GABET, 2007)

The rocky substrate that occupies the entire central portion of the municipality is formed by migmatites, gneisses of granitic, tonalitic and granodioritic composition of the Bação Complex, which has a domic aspect and shear characteristics at the edges (DORR, 1969). The second domain is formed by rocks of the intensely metamorphosed Rio das Velhas Supergroup, which includes green rocks, rhyolitic lavas and interspersed sedimentary rocks (CHEMALE, 1991). The third domain is made up of rocks from the Minas Supergroup, which is a metasedimentary sequence, consisting of four groups, overlapping in disagreement with the Rio das Velhas Supergroup.

At the base are found quartzites and conglomerates of the Caraça Group, covered by phyllites of the Batatal Formation. Overlapping is the Itabira Group, characterized by the Cauê Formation BIF, graduating to the Gandarela Formation, with the presence of carbonate rocks. Finally, overlapping the entire sequence is the Piracicaba Group, with several Formations in which deltaic / metapelitic sediments predominate (ALKMIM, 1998). Due to lithostructural characteristics, these rocks become more resistant with greater distance from the central area, in a more or less semi-concentric arrangement model, to the outermost regions, although less resistant rock intercalations occur within these sequences. In general, it supports the arrangement of the Geomorphological Units (Figure 7) for the higher Units, although it does not demonstrate this close relationship with the other Units. This indicates, as pointed out by (Barthelos (2007), that the interrelationship between lithology, relief form and the occurrence of geomorphological processes needs to be relativized, as other variables come to control these processes from the moment the valley is opened and the slopes are formed, the ground is developed and the vegetation covers occupy the valley slopes and bottoms. Similarly, the variation of climatic domains along the evolution of a given relief varies, with different responses in terms of dominance of rock alteration processes and their effects on the dynamics of the relief.

The Map with the results of the Roughness Concentration Index (RCI), which aims to quantify and classify the relief units based on the spatial distribution of their gradients (Figure 3) indicates the presence of coincidental higher values, generally in contact between rocks differing in resistance.

However, the higher RCI correspond to the areas where the most effective relief notching occur promoted by springs what favors the presence of more rugged and steeper landforms. The highest Roughness Concentration Indexes (RCI) are found following the internal edges of Serra do Itabirito facing the Rio das Velhas valley and in the north-eastern portion of the municipality, in the Sinclinal Gandarela domains. These are areas of intense dissection due to the large number of springs and the steeper slopes. Another observation refers to the lower RCI values, which correspond to the lower portions of the Rio das Velhas valley, where the hillsides tend to become shorter due to the increase of deposition and accumulation of sediments on terraces. Despite occurring in sections of rivers with recently dug channels, they are still insufficient to be mapped on this scale of work. Lower RCI values are also observed (Figure 4) in the region where the gullies are concentrated on slopes with milder gradient and subjected to intense land use, with possible effects on base levels of the river and loss of vegetation cover leading to intensification of this type of accelerated erosion. In the composition of the weights for the Multicriteria Analysis, this variable received a weight of 25%, since places where the slope is very steep, once occupied, become potential risk areas.

The Hack Index (HI) Map (Figure 4) summarizes the energy of drainage basins (FONSECA & AUGUSTIN, 2011), constituting an important attribute of geomorphological analysis, since the energy of the basins is one of the most important morphometric components and is widely used for understanding the dynamics of the earth's continental surface. This index was established by Hack (1957), in which he relates the slope and the extension of watercourses, through the bivariate representation between the elevation and the length of a given river course from upstream to downstream.

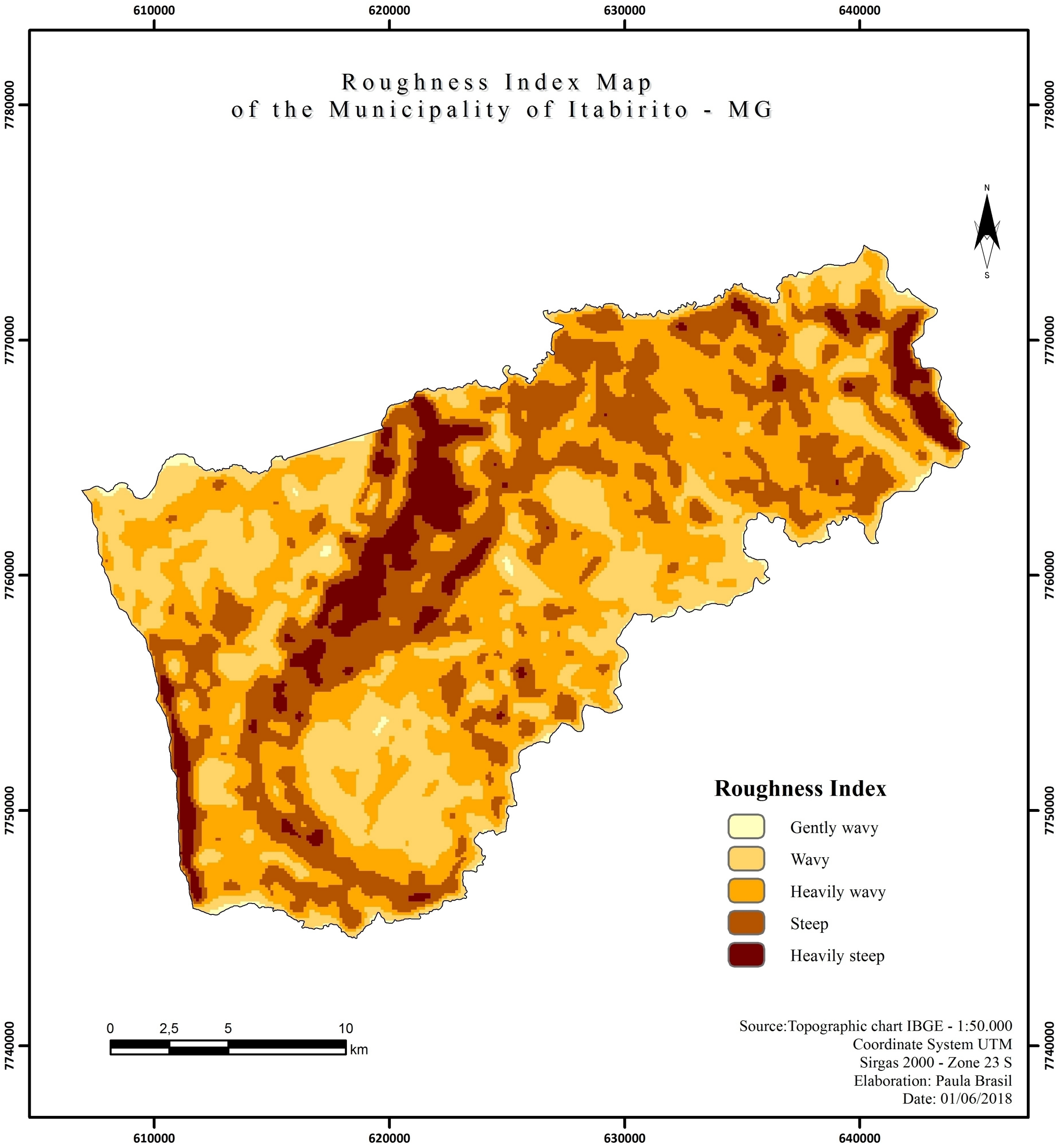

Figure 3 - Roughness Index Map of the Municipality of Itabirito

Therefore, they are associated with the presence of knickpoints, which point to abrupt changes of slope and enable the formation of waterfalls when they occur perpendicular to the channel. Intermediate HI values also occur in areas of river heads, where higher dissection energy is expected, due to their gradient, which tends to be higher in these areas. The most representative knickpoints are present in areas of litho structural contacts, or between steeper areas and valley bottoms, in many cases occurring abruptly, as on the Moeda Plateau. The lowest HI values correspond to areas in which dissection is hampered by the presence of iron duricrusts , or in the lower portions of the Rio das Velhas basin, areas that also have a smaller number of knickpoints due to the smoothness caused by the erosion over geological time,

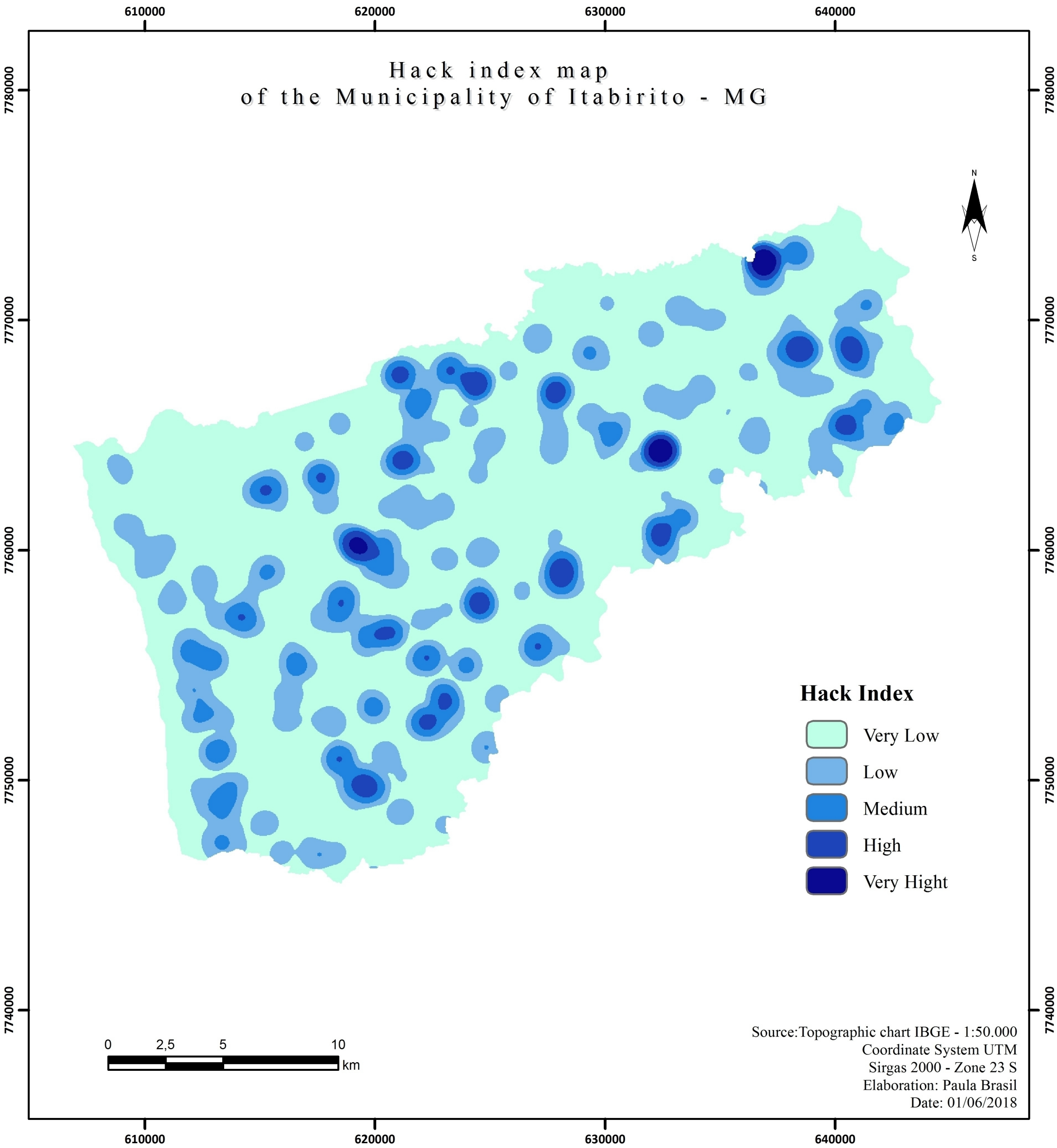

Figure 4- Hack index map of the Municipality of Itabirito

The Map of the concentration of gully (Figure 5) was elaborated because of the high frequence of this erosion form associated with geomorphological process in the municipality, especially in the southern portion, near the São Gonçalo do Bação district, where, dominated by hills with altitudes below 1.000 meters, one of the highest concentrations of gullies in Brazil is observed (LIMA, 2016).

Silva (2007) attributes this agglomeration to the presence of a morphologically unstable environment, with different sizes and shapes, on terrains developed on granite gneiss. For Bacellar (2000), the appearance of these features occurred from the beginning of the gold cycle, with the installation of rudimentary agricultural practices that aimed to produce food for the gold provinces of Vila Rica, Mariana and Sabará, which may have corroborated the emergence of these erosion processes in the Bação Complex region. The same author found gully scars in the region, but most of the current, active and inactive scars have formed in the last two centuries, reinforcing the interpretation of anthropic interference. Parizzi et al. (2011) states that when weathered granitic and gneissic rocks produce silty-sandy or silty-sandy clay residual soil, which, due to its low cohesion, it become highly susceptible to erosion and similar processes. Work by Figueiredo, et al (1999), however, indicates the existence of more complex mechanisms in the regolith associated with the effect of iron on the structuring of clays in larger particles, increasing the collapsibility of the geo-coverings structure. Augustin & Aranha (2006) also point out that this mechanism favors the action of pore pressure, facilitating piping and gully formation. For Parizzi et al. (2011), in these environments, caution should be exercised when executing cuts, earthworks, and deforestation, the consequence of which is the exposure of these soils to the action of runoff, especially in hilly regions with concave and well-drained areas, such as the gullies region of Itabirito. They also have steep walls and promote the process of adaptation of new plant lifeforms, thus developing a local ecosystem (Silva, 2007). In the study region, this area is sparsely occupied, but is in the process of expanding. If there is no intervention by the government in the management of use and occupation of these areas, the buildings already installed are susceptible to risks, as can be observed in figure 6 (a, b), showing houses near an active gully. This variable received a 10% weight in the Multicriteria Analysis due to its occurrence in a smaller area in the city, besides being conditioned to occur due to other factors such as use and occupation, geology and geomorphology.

The Map of Geomorphological Units seeks to meet the proposition of a more integrated and contextualized view of the biophysical aspects of the study area, (Figure 7) expressing the structuring of the relief. These relief forms are intrinsically associated with the processes that acted and still act on them, and their compositional materials, whether rock or geo-coverings, including soil. Five landscape component units were identified, each with its own geology, geo-cover, vegetation and susceptibility to erosive processes and mass movement characteristics.

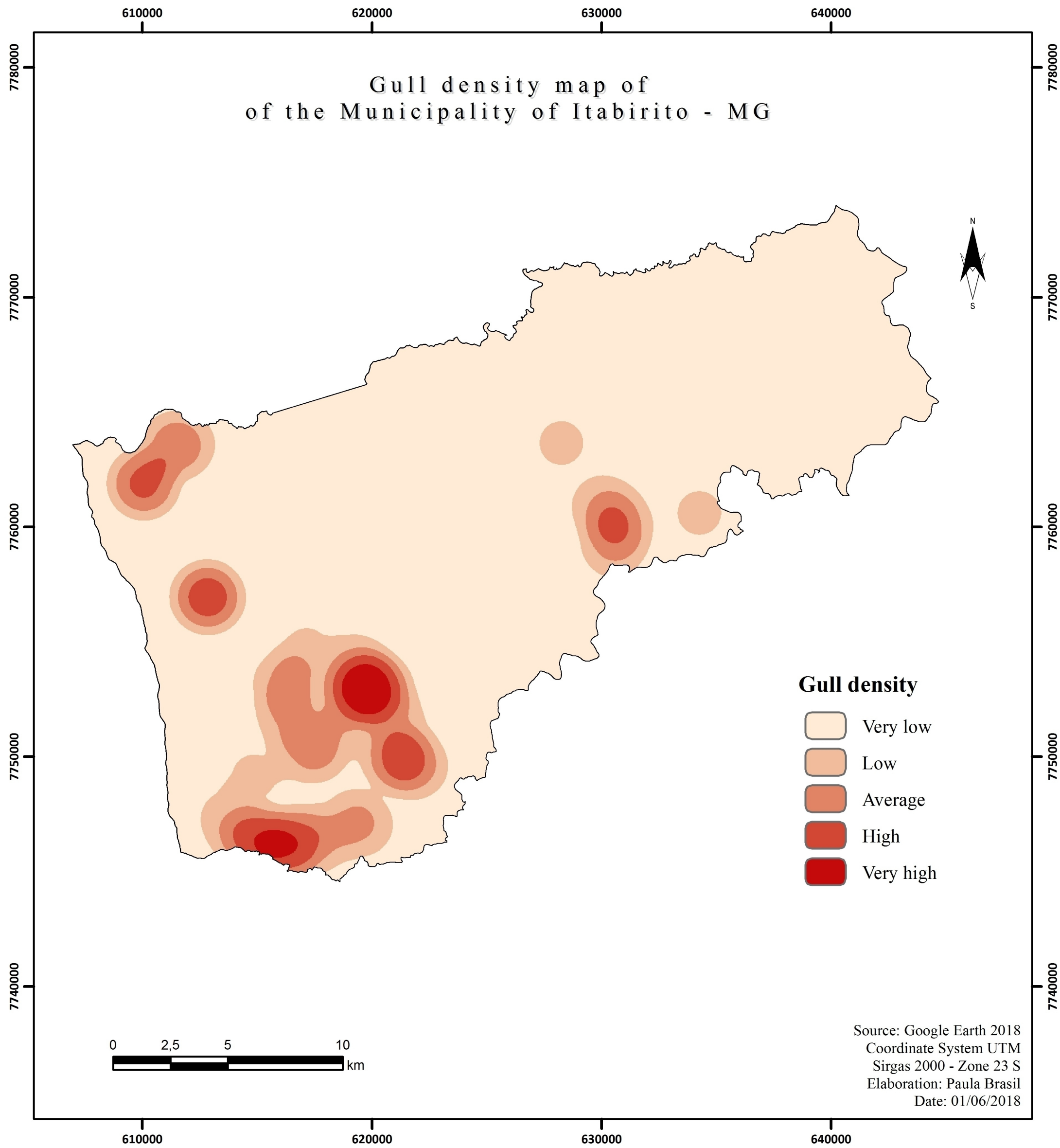

Figure 5 - Gull density map of the Municipality of Itabirito (Source: Google Earth, 2018)

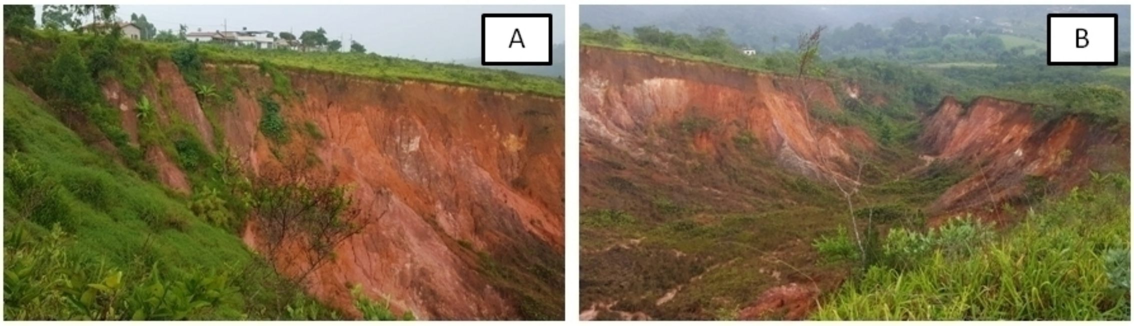

Figure 6 (a,b) - Gullies located near São Gonçalo do Bação district and buildings. It can be observed that the slopes are steep and small mass movements occur, besides a heterogeneous distribution of vegetation with predominance of small shrubs in the middle and lower portion of the gully, insufficient to contain the geomorphological process. It moves further toward reassembly (A), while downstream it is narrow and seated.

Because they are easily identifiable on any means of land surface representation (geoprocessing instruments), and also present features that even when is altered by man, tend to remain on the landscape, the relief forms and their representations are important elements when it comes to composing a reliable data base for spatial analysis for various purposes (HAANTJENS, et al., 1972; COOKE & DOORNKAMP, 1974; AUGUSTIN, 1979; CARTON, et al., 2005). They are:

a) Elevated Residual Surface - formed by the tops of the Cauê Formation's folded rock chains of the Itabira Group, and the Moeda Formation quartzites of the Caraça Group, they are located on the east and west edges of the municipality, and are represented respectively by the Sinclinal Gandarela and the Serra de Itabirito. These mountains, with altitudes between 1620 and 1740m are, according to Barbosa (1980), raised synclines, remnants of ancient geological structures subjected to inversion of relief. They have low geochemical denudation rates in relation to the other units due to the extensive presence of lato sensu (l.s) laterites, as proposed Augustin, et al. (2013), which contributes to the maintenance of the highest portions of the relief. The presence of these iron duricrusts regionally known as "cangas" , and their relative convexity influence the low infiltration rates of runoff, Due to the resistance of these coverings and also that of quartzites to low chemical weathering rates, even in the hot and humid conditions of area the relief presents several outcrops, especially in the quartzite domain. Litolic Neossol soils predominate, while in the areas of itabyritic rocks, exposed laterites formed by rock fragments consolidated by iron-rich matrix are the most recurring features although there are also Litolic Neossols present, which are characterized by a dark red color, rich in iron and very stony. According to Carvalho Filho, et al. (2010, p. 915) "the soils related to the ferruginous dolomites of the Gandarela Formation also have very high manganese oxide contents, which are associated with very dark colors". Along with altitude, the presence of duricrust and very iron-rich soils favors the occurrence of ferruginous rock vegetation type that contain also lichen cover and altitude fields, as noted by the above authors,. The largest vegetation of shrubs and grasses occurs only at the bottom of incipient valleys of temporary watercourses that managed to erode the duricrust cover, exposing the dolomitic shales and itabirites. Due to the higher altitudes, the elements of this Unit function as large watersheds.

b) Flat Top of the Intermediate Level occupies the northwest and northeast ends of the municipality, with altitudes between 1618 and 1373m, forming lower topographic levels than those of the previous domain. These are areas in which the highest erosive plateaus of the Ribeirão do Silva valley stand out, which were, and continue to be, modeled by drainage incision and reshaping of the slopes, although they have lower drainage density than the other Units, as can be seen on the drainage density map in figure 8.

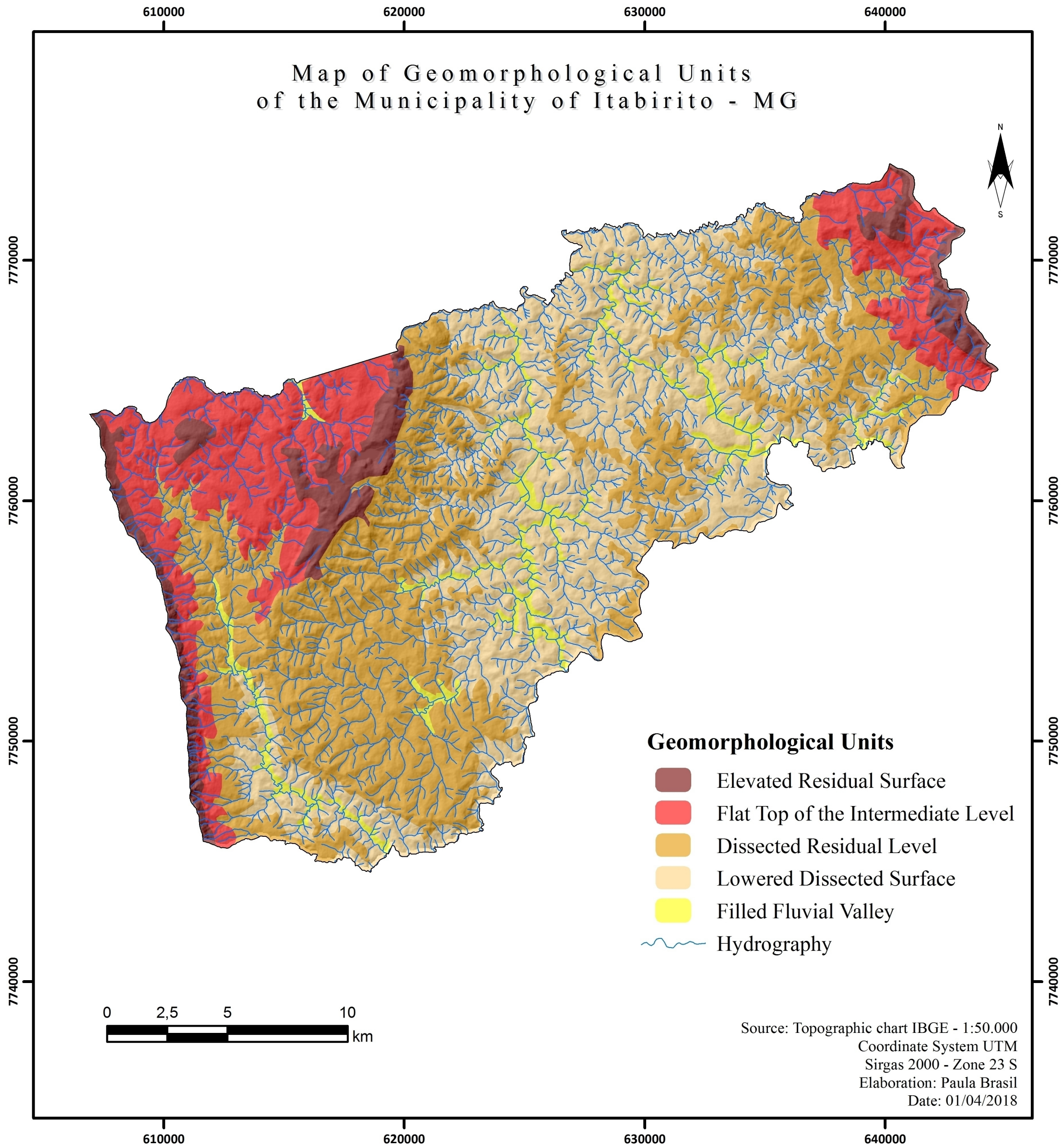

Figure 7 – Map of Geomorphological Units of the Municipality of Itabirito

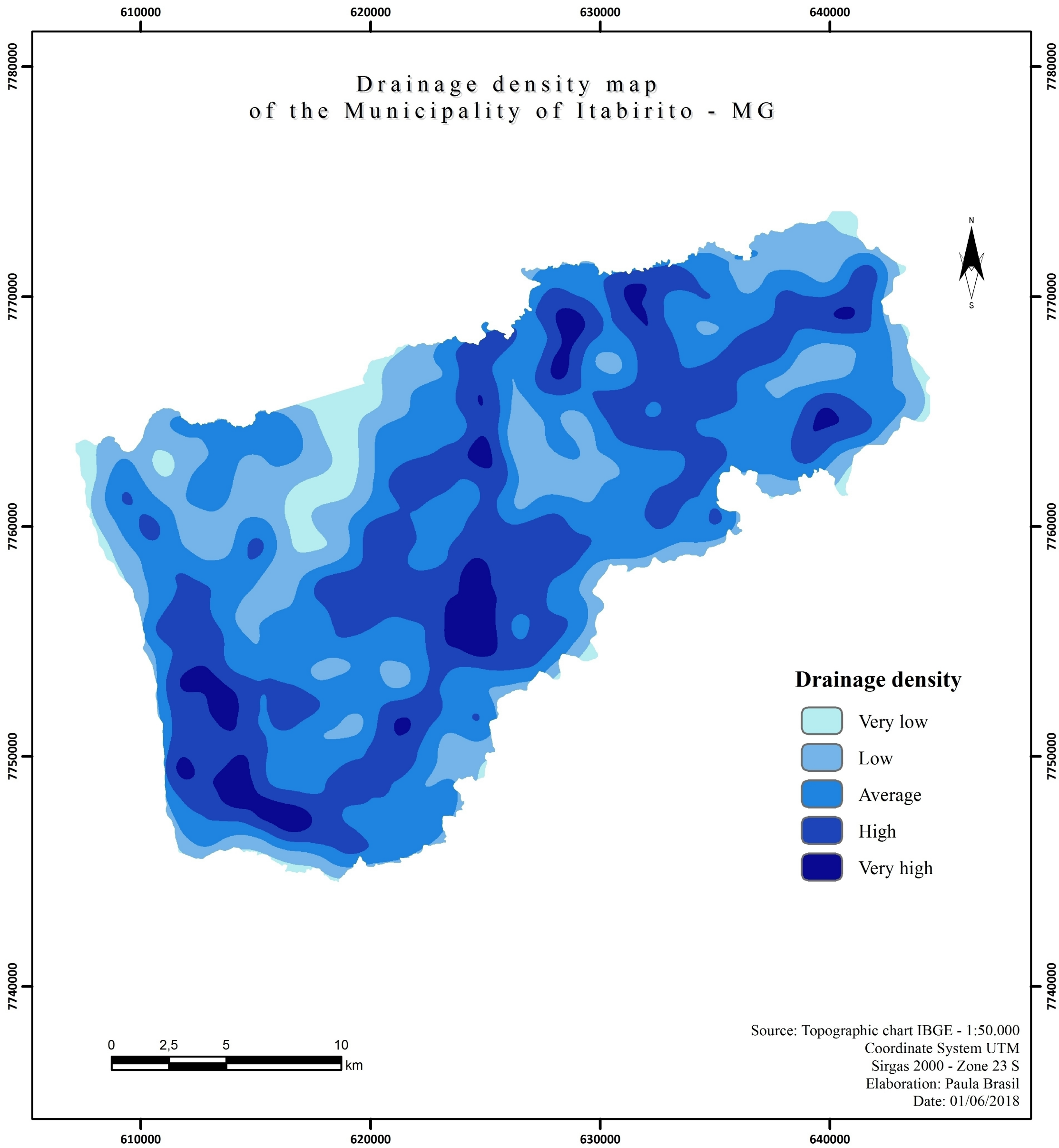

Figure 8 - Drainage density map of the Municipality of Itabirito

The presence of these relief forms in topographically lower portions than Unit I (High Residual Surfaces) is due not only to the greater susceptibility of these rocks - predominantly phyllite, dolomite, itabirite, and iron duricrust to the weathering process, and consequently to erosion, but also because they are located stratigraphically below the rocks that make up the highest parts of the relief (itabirites, iron duricrusts, and quartzites). Because they are in a space adjacent to the tops of the synclines, they have steep slopes at the valley bottoms, although their tops are wide and flat, indicating the possibility that they are residual reliefs of previous pediment preserved due to the difficult incision of drainage. This fact is corroborated by Carvalho Filho, et al. (2010), who indicate the presence of poorly developed soils with high percentage of stoniness, with Lithic Neossols and Cambisols of perferric character standing out, "with extremely high iron contents, distinctive of perferric character", and "intense red color, in some cases with a darkened shade" (p. 907). In part of Serra da Moeda, the same authors also identified the presence of thick masses of stone fragments cemented by ferruginous matrix, with soils that can be classified as concretionary metric Plossosols, as well as the presence of Perferric Red Latosols. Another factor contributing to the maintenance of these surfaces is the largely oxidized iron-rich geo-toppings. They are landforms occupied by ferruginous-like rupestrian field vegetation, especially in areas with the presence of stony masses of ferruginous matrix that alternate with low scrubland and sparse shrubs, with a predominance of grasses in very weathered itabirite outcrops. Because of the ferruginous matrices, which in parts of the slopes are hardened, forming laterites (l.s.), the surface runoff processes act by undermining the base of the duricrust outcrop contributing to its collapse and fall. These are areas that, due to their location between the tops and bases of Unit I which is topographically higher and with greater declivity (Figure 3) are highly susceptible to erosive processes, although their geo-coverings tend in the short and medium term to increase cohesion due to iron oxidation, an element present throughout the altered profile, whether eluvium, or colluvium. These are areas, therefore, that from the geotechnical point of view, have potential use for occupation by buildings, but that from the perspective of the set of factors under analysis, should be preserved. This is reinforced by the occurrence of erosion caused by concentrated runoff that creates temporary flows at the edges of the iron duricrust and / or itabirite domains, both inside and outside portions of the sierras, removing the concrete surface portions of the iron duricrust undermining its bases and leading to breakage and occasionally to displacement due to the force of gravity. These areas are therefore unsuitable for use and occupation as they pose a risk of movement of iron duricrusts blocks. In addition, they constitute spring areas that should be preserved as future potential for drinking water supply. The relative flat tops, lithology and structural characteristics of the region enhance infiltration of runoff water, turning these areas into good water retainers that feed stream springs and streams. These are areas of water reserves presenting, therefore, potential use as natural resources for water supply to the urban area.

c) Dissected Residual Level - topographically constitutes lower levels terrains than those of Unit II (Intermediate Flat Top Level), with altitudes between 940 and 1,460 m, already eroded and dissected, due to the high concentration of the drainage system. This level is mainly formed on dolomitic metarenites, shales and phyllites and presents average rates of geochemical denudation. It is the second largest unit in terms of area and occupies all portions of the Serra da Moeda internal plateau and the Rio das Velhas River basin. In these domains, Carvalho Filho (2010) indicates the predominance of gravelly, clayey Cambisols, rich in iron and, more rarely, red to yellow Latosols found in colluvial deposits, on the low slopes of Serra da Moeda and Itabirito. In the steepest portions, the author (op. Cit.) identified the presence of litholic and regolithic lithosols. The vegetation cover within this Unit varies depending on water availability and soil development. Grasses of the clean field type predominate, alongside ferruginous rock vegetation, with the presence of forests that accompany the most embedded valley bottoms. The most frequent geomorphological processes, partly due to the more open vegetation cover and the steep slope on slopes of embedded valleys, are dispersed erosion, caused by surface runoff and, on some slopes, gullying. This increased vulnerability and the combination of more susceptible rocks to chemical weathering, occasionally steep slopes, predominantly undeveloped soils, and the occurrence of concentrated erosion by superficial runoff, indicate that these areas may have a problematic urban use.

d) Lowered Dissected Surface - unit characterized by relief of rounded hills and embedded valleys, located at topographically lower levels of the basins of the Peixe River and the Ribeirão Mata Porcos, later called the Itabirito River, which flows into the Rio das Velhas River, occurs at altitudes between 760 to 1,120 m. These are areas of crystalline rocks of the Itabirito batholith domain, which present intense chemical weathering. Occupying the intermediate topographic positions between the Valley Bottoms and Dissected Residual Level this Unit sometimes has steep valleys with abrupt walls, indicating recent erosive reactivation. The soils, according to Carvalho Filho et al. (2010, p. 46), accompany the relief, with the predominance of Red Latosols on convex slopes and Cambisols on the lower slopes. It is also a Unit in which gullies occur, associated with past mining activities (ROESER & ROESER, 2010) and even with agricultural activities. The presence of gullies compromises land use and occupation, as well as contributing to the silting of fluvial channels in the area.

e) Filled Fluvial Valley - a unit characterized by seasonal fluvial processes of erosion and deposition, with high sedimentary load, partly resulting from eroded material from gully densification, largely caused by anthropogenic actions, including inappropriate use and occupation of areas for construction, openings of neighboring roads, changes in the course of rivers, streams and creeks, and mining, among others. However, as pointed out by Bacellar (2000; BACELLAR et al., 2001), their occurrence is strongly conditioned by crystalline lithologies of the Bação Complex. This unit has two subunits, the terraces and the river channels. Although all occur in the area of influence of river dynamics, terraces also tend to be subjected to the processes of the hillslopes, with deposition of sediments from their upper portions. In exceptional cycles of high rainfall, they may suffer erosion from the river flows and are potential areas of risk due to flooding. On older, stable terraces, less subjected to seasonal flooding, Cambisols and even Red Latosols can be found, while on the newer terraces Gleyssolos are found. Closer to the channels, and even within the channels, are Fluvic Neossols which are usually Arenic.

MAP OF GEOMORPHOLOGICAL INDEX OF LAND USE AND OCCUPATION POTENTIAL

This map is the result of an approach that addresses aspects pointed out by Zahra & Khorshiddoust (2011) and Bathrellos (2007), for whom there has been a simplification in the studies on urban geomorphology, with emphasis on geology, that is, aspects of the physical behavior of materials, which have general operating laws. This is because, according to the last cited author (p.1360) "the changes in urban environments caused by humans is such that it supersedes or suppresses natural processes, which makes it necessary to adopt new techniques." For this author,

Urban geomorphology combines the ambient geology, landforms, and geomorphological processes with the evaluation of impacts brought to these by urbanization. The practitioners of urban geomorphology tend to concentrate on alteration, using the ambient physical environment as a baseline. A number of case studies from different parts of the world (dealing with topics such as slope instability, seismic hazards, increased flood problems, and land subsidence) have demonstrated the utility of urban geomorphology to engineers, city managers, and urban planners (GUPTA & AHMAD, 1999).

Thus, the Map (Figure 9) is an integrated representation of the potential use of the different components of the landscape, based on the understanding that the relief forms bring together several important aspects of the environment, since they influence and condition: 1) runoff / infiltration of rainwater with effects on erosive potential on slopes (MORISAWA, 1959; YOUNG, 1972; CARSON & KIRKBY, 1972; GRENWAY 1987; ALEXANDER, 1991; TUCKER & BRAS, 1998; BARBOSA & AUGUSTIN , 2000; HUDSON et al., 2015; BACELLAR, et al., 2001; SOULSBY, et al., 2006; WIITALA, 1961); 2) the instability of the slopes and their responses in the form of mass movements, even in rocky massifs; (MORISAWA et al., 1994; ALCANTARA-AYALA, 2002; GABET, 2007; MONTZ & TOBIN, 2011); 3) the transport / siltation of river channels (WOLMAN & SCHICK, 1967; LEOPOLD, 1968; GUPTA, 1984,1999; EBISEMIJU 1989; MONTGOMERY, et al., 1995; SEAR et al., 1995; TRIMBLE, 1997; TUCKER, et al., 1998; BOOTH & HENSHAW, 2001; URBAN, 2002; CLARKE et al., 2003; SKILODIMOU, et al., 2003; DOWNS & GREGORY, 2004; ALBERTI, et al., 2007; GREGORY et al., 2008); 4) the water table, which tends to accompany relief (RODRÍGUEZ-ITURBE & VALDES, 1979; BROWN, 1996; RAJAVENI, et al., 2017); 5) the development of geo-coverings, understood here as all the material present on the slope, from the surface to the bedrock, including the pedological soil; and, thus, 6) vegetation cover, affecting both ecosystems (QUEIROZ NETO, 1989), as well as the potential for urban occupation (CARSON & KIRKBY, 1972; CHRISTIAN, 1982; ANTONY, 2001; CUNHA, et al., 2003; ALBERTI, et al., 2007; BATHRELLOS, et al., 2012). Also, the relief units / forms, due to their integrative character (BRUNSDEN & THORNES, 1979; THORNE, et al., 1997; ANTONY, et al., 2001; BONHNET & PERT, 2010; BATHELLOS, 2012; THORNBUSH, 2015), are used as elements of spatial analysis of land management potential (VERSTAPPEN, 1983; HUDSON, 2015; THORNBUSH, 2015); and 7) natural resources, as indicated by methodologies based on geomorphological taxonomic units of varying scales that enable the mapping of land use and occupation potential (HAANTJENS, et al., 1972; LOFFLER, et al., 1972; SAUNDERS, 1973; GRANT & FINLAYSON, 1978; AUGUSTIN, 1979; BURROUGH, 1986; BOCCO, et al., 2001; PARO & SMITH, 2008; DOWNSAND & BOOTH, 2011). In this sense, Cooke (1976, p. 59) draws attention to the fact that geomorphology can assist in the management and development of urban areas in two ways: one, in the assessment of potential resources and suitability of areas being considered for urban development. The other would be through “monitoring process-response systems, and their changes during and after urban development, with a view to establishing a theoretical body and empirical data that can support the management strategy and at the same time assist in predicting changes that may arise from future urban growth.” (COOKE, 1976, p. 59)

As can be seen on the final map (Figure 9), the region that obtained the greatest potential is the

Bação complex, a region that has granitic rocks, with geotechnical characteristics favorable to occupation. However, in the southern portion of the map, it is noteworthy that this region had medium to low potential, especially where the district of São Gonçalo do Bação is located. Despite the favorable conditions from the geotechnical point of view and presenting low roughness index, as indicated on the Map of Geomorphological Units, it is a region that has intense erosive processes that make urban use and occupation difficult. In this sense, the results obtained for this region are justified due to the high grade of the subtitle component of the geomorphological variable - Dissected Recessed Surfaces - and the weight of the variable itself - Geomorphology - also being high.

The lowest potentials for use are concentrated in the Flat Top Intermediate Level Unit, which has low drainage density and spring areas. These are areas that may, as a function of the geomorphological location below High Residual Surfaces, be considered as potential hazards due to iron duricrust block displacements, as indicated by the Relief Geomorphological Units analysis (Figure 7). They are also areas with a concentration of inadequate mining activities, and are, therefore, inadequate for urban expansion.

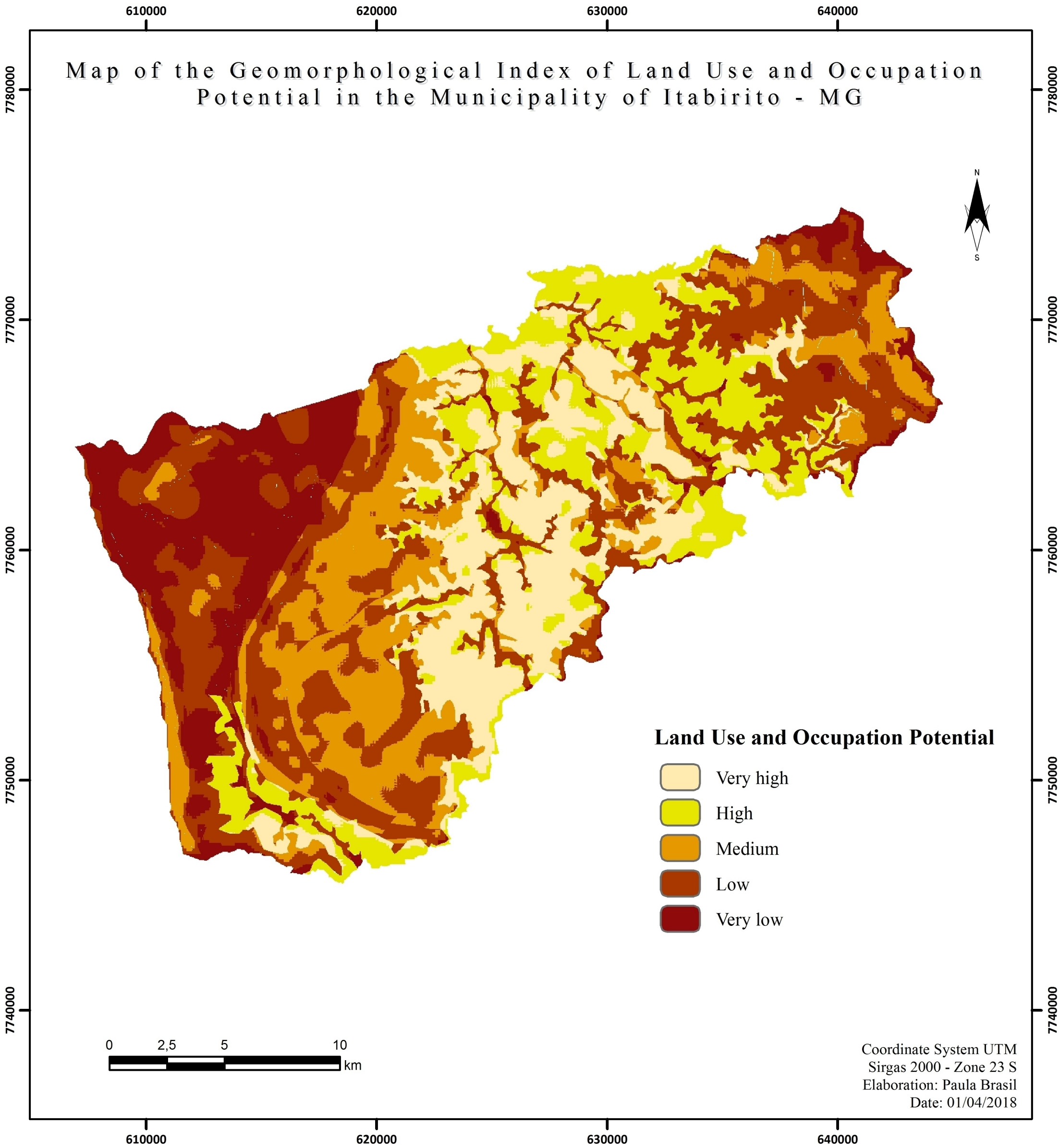

Figure 9 - Map of the Geomorphological Index to evaluate the Land Use and Occupation Potential in Itabirito - MG.

Interestingly, the RCI values (Figure 3) in the north-western portion of the Flat Top Intermediate Level domain are not as high as in the eastern part of the Serra do Itabirito, where metarenites dominate, indicating that despite the high altitude, it is difficult for drainage to dissect rocks of this lithology. The largest RCIs comprise both the Residual Tops Unit and part of the Dissected Residual Level.

CONCLUSION

Urban planning and management instruments, especially Master Plans, do not adequately address physical variables such as relief. Knowledge of this, as well as its modeling agents, is essential, especially to avoid occupation of inappropriate places and potential for formation of risk areas, which later becomes a challenge for the management of cities, as they become consolidated areas.

Through the data collection and production of the variables used in the elaboration of the Geomorphological Index, it can be affirmed that in the planning process of cities, it is necessary to know the geomorphological variables linked to the physical environment. This knowledge would enable the prediction of risk situations such as areas susceptible to flooding, slippages, and landslides, among others.

Thus, there is a need for knowledge on local territory so that the municipality can better explore its land use and occupation in order to generate improvements for the population and draw up a Master Plan with high-level knowledge depending on the geographical location in which it is inserted.

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