GIS-BASED ANALYSIS OF THE LAND COVER RELATIONSHIPS WITH SLOPE GRADIENT AND FOREST PATCHING IN VOTORANTIM MUNICIPALITY-SP

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Abstract

Considering the importance that the information concerning land cover has in the investigation of some kind of risks and also about the comprehension of the process of forest patching, this study aimed studying the relationships among land cover and slope, as well as the patching situation of the Remaining Natural Vegetation of the Votorantim Municipality, São Paulo State. For developing the study a digital land cover map (2003) and the Digital Elevation Model were used. The study was carried out through GIS technology, being the Idrisi (Kilimanjaro version) the software employed. The main results point a favorable situation of land cover with relation to relief characteristics. Few areas were considered inadequate cover or with risks. On the other hand, it was registered patches considered small and with few opportunities for maintenance of the original pattern of biodiversity, unless an efficient connection among these patches takes place, in order to promote the wildlife transition among the patches.

Key-words*:* Land cover. Environmental risks. Forest fragmentation. Votorantim-SP-Brazil, Geographic Information System.

Resumo

Análise baseada em SIG sobre as relações entre cobertura do solo e relevo e sobre fragmentação florestal em Votorantim-SP

Considerando a importância que a informação sobre cobertura do solo possui sobre alguns tipos de riscos a também sobre a compreensão do processo de fragmentação florestal, objetivou-se estudar as relações entre a cobertura do solo e o relevo, bem como a situação da fragmentação florestal da Vegetação Natural Remanescente do município de Votorantim-SP. Para o desenvolvimento deste trabalho utilizou-se o Modelo de Elevação Digital e um mapa de cobertura do solo de 2003. O estudo foi desenvolvido através de técnicas de geoprocessamento e utilizando o software Idrisi (versão Kilimanjaro). Os principais resultados apontam uma situação favorável de cobertura do solo em relação às características do relevo. Ocorreram poucas áreas consideradas de risco. Por outro lado, registraram-se fragmentos florestais considerados pequenos e com poucas oportunidades para manutenção dos padrões originais de biodiversidade, a menos que uma efetiva conexão entre estes fragmentos seja estabelecida, visando promover a transição de animais silvestres entre os fragmentos.

Palavras-chave: Cobertura do solo. Riscos ambientais. Fragmentação florestal. Votorantim-SP, Sistema de informação geográfica.

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INTRODUCTION

Slope is a topographic element of the landscape that expressively influences various hydrological and geomorphologic processes and governs the environmental dynamic of a region (ROSS, 2003). Therefore, the knowledge of the slope classes of a region is important because it aims to meet the specific legislation for the land use planning, as one of the most important physical factors that generally limits the human occupation of a region (PINTO et al., 2005).

In turn, land cover also exerts significant influence under many manners of the environmental dynamic, as human activities usually alter the topography and biogeochemical cycles dynamics through activities that trigger impacts such as erosion and sediment transportation, fires, launching of pollutant products in the atmosphere and water resources, among others (LAMBIN et al., 2003).

Investigating relations between the land cover and physical factors of the environment is of paramount importance, both in the urban context as in the rural context, since land use conflicts commonly occur due to socio-economic issues, educational, cultural and historical, characterizing a complex interaction of physiographic and socio-economic factors in a region (FU et al., 2006).

Interactions between the various environmental factors, most notable the climate, topography, soils, geology and soil cover in a specific region can be carried out with the use of Geographic Information Systems (GIS). This technology enables the storage and management of collected and generated data, with speed and precision, and it allows the identification of susceptible areas for environmental degradation and the evaluation of management strategies before they are adopted (PINTO et al., 2005).

The result of this interaction may be represented by cartographic instruments denominated risk maps. A map like this can be compared with others to identify areas with greater or lower risks of having social, economic and / or environmental impacts consequences due to irregularities in the land use in relation to the characteristics of the local topography (OLIVEIRA; BRITO, 1998).

On the other hand, fragmentation of forests is another process that is going on a large scale and can be investigated with some success through the analysis of land cover maps and GIS techniques (GOODCHILD, 2003). Such technology permits the analysis of spatial pattern of the mosaic of the landscape, checking the average area of the forest patches, establish the numeric value (proportion) between habitat and non-habitat for wildlife (SILVA, 2004b), among others factors.

The city of Votorantim-SP, place of interest in this study, is an important corridor of biodiversity called “Biodiversity Corridor of the Serra do Mar”. As a state or a country, the Corridor area of Biodiversity is defined by an imaginary line. Within these limits there is a great biological diversity, considered a hotspot for biodiversity (SOS ATLANTIC FOREST FOUNDATION, 2008). Additionally, Votorantim aims to become an important ecotourism pole in the region because of its richness in water resources and landscapes. This indicates the importance of preserving natural resources in a region and preparing studies of this subject.

The aim of this work was to study the relations between the land cover and the slopes, as well as analyze the patching stage of Remnant Natural Vegetation in Votorantim.

STUDY AREA DESCRIPTION

The Votorantim Municipality is located in the southeast portion of the São Paulo State, Brazilian Territory (Figure 1). It has an area of 184.0 km^2 and a population of approximately 100,000 inhabitants (IBGE, 2008). Votorantim is situated in a Unit Management of Water Resources (UGRH) called "Sorocaba-Middle Tietê" (SIGRH, 2008), which is classified as industrial by Cetesb (CETESB, 2008).

According to Köeppen's classification, the climate of the region is considered as "Cfa" (humid subtropical), with the annual average temperature of 21.3^{o}C and 1,287 mm of annual rainfall depth (EMBRAPA, 2008). In the region, Ultisols is the predominant class of soils, but the Oxisols also occurs in some portions of the municipality (OLIVEIRA et al., 1999).

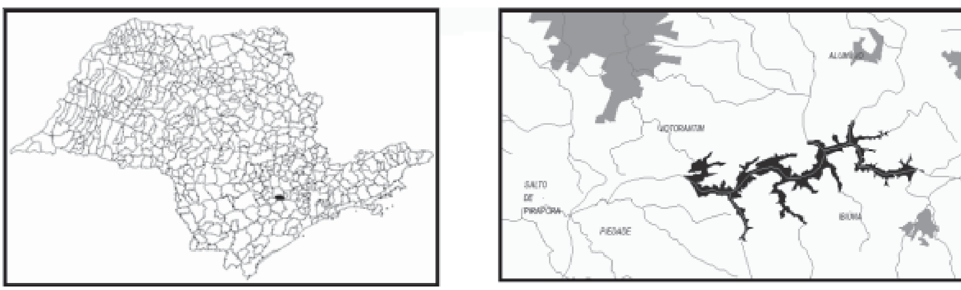

Figure 1 - Left: São Paulo State municipal map showing location of Votorantim Municipality. Right: Location of the municipality of Votorantim (SP) in the state of São Paulo (left), its hydrograph and urban area. Gray patches: urbanized regions. Black patch: Itupararanga Dam

Source: www.biota.org.br

There is a predominance of the class between 600m to 700m and higher altimetry classes occur predominantly in the eastern portion of the municipality (BOMBACK, 2007). According to Bomback (2007), land cover is comprised mainly of pasture, with expressive occurrence also in areas with reforestation (most notably in planted areas with *Eucalyptus* sp. for use in paper and cellulose industry), as illustrated in figure 2 and table 1.

The industry sector provides a significant source of income (sectors of textiles, paper, cardboard, pulp, lime, packaging, various equipments, including electronics and, in particular, Votoran cement, recognized in whole Brazilian territory). Votorantim still depends on the cultivation of various agricultural products, especially fruits and vegetables (commonly small rural proprieties). It has also beef and dairy cattle, poultry and other animals. Its local market appears to be significantly active and varied, satisfying the needs of the regional population.

In figure 2, it is possible to observe a large blue spot in the southern portion of the city, which corresponds to a part of Itupararanga dam. This dam is formed by the Sorocabuçu, Sorocamirim and Una rivers, that after grouped, they form the Sorocaba River. The dam was built in 1911, it has a drainage area of 851 km^2, maximum flow rate of 39.1 m^3.s^{-1} and currently it has the purpose of multiple uses (water for irrigation and urban supply, recreation and nautical sports, among other uses). Due to the great importance of this dam for the region, it was set in 1998, the creation of the Environmental Protection Area of Itupararanga, involving the municipalities of Votorantim, São Roque, Mairinque, Ibiúna and Piedade (SEMASP, 2008).

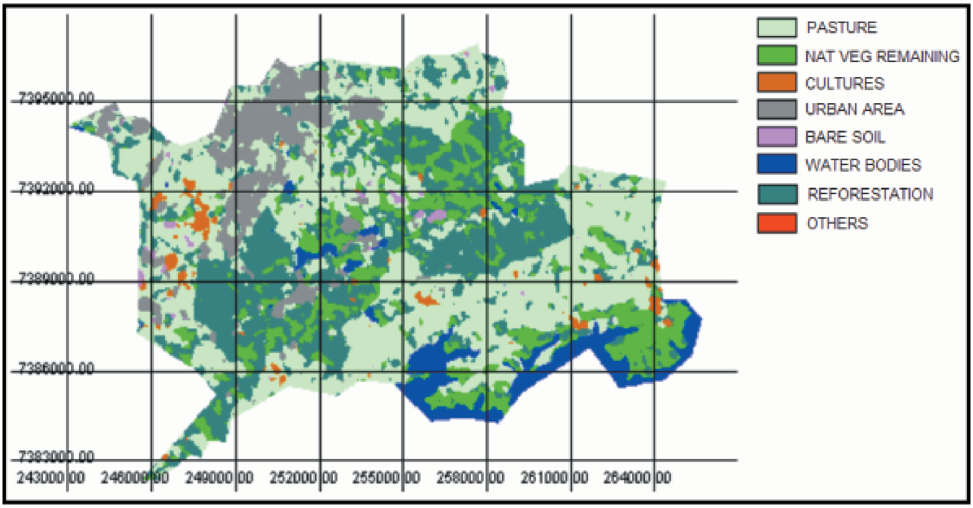

Figure 2 - Land Cover map of Votorantim –SP

(coordinate system: UTM (23-S))

Table 1 - Percentages of occurrence of each land cover class in the municipality of Votorantim

Class of land cover	Occurrence (%)
Pasture	39.9
Remnant Natural Vegetation (RNV)	14.8
Crops	1.7
Urban area	9.8
Bare soil	0.6
Water Bodies	5.7
Reforestation	27.5

PROCEDURES

Slope and Land Cover Maps

The work was carried out through GIS techniques, and the Idrisi (version kilimanjaro - EASTMAN, 2004) was the main software used.

The Digital Elevation Model (DEM) of the study area was acquired from Imagem enterprise (SILVA, 2004a). The enterprise informed us that the DEM was elaborated using topographic maps (scale: 1:50,000) elaborated by Brazilian Institute for Geography and Statistic (IBGE). The slope map was elaborated using the DEM and the *Surface* command of Idrisi, with subsequent reclassification into six slope categories. For this classification, the relief was considered “plane” on the regions whose slope value varied from 0 to 3%; “smooth” from 3 to 8%, “waved” from 8 to 20%, “strongly waved” from 20 to 45%, “mountainous” from 45 to 75%, and “steep slope” for values greater than 75% (SANTOS et al. 2005).

The land cover map was obtained from Bomback (2007), which was prepared using a satellite image of Landsat-5 (path/row 220/76), taken in May 15, 2003. The land cover map includes the following classes: pasture, remnant natural vegetation, crops, urban area, bare soil, water bodies and reforestation (see Table 1).

Cross-tabulation analysis

With the slope and land cover maps, it was realized the intersection of these maps using the "Cross-tab" command of Idrisi. The new map was reclassified according to the categories exposed in table 2, cited below. The explanation of each interpretative class is showed below and it was based on Silva (2001).

Water bodies – it is represented by small lakes and rivers that occur along the study area.

Adequate cover - represents all land cover categories compatible with the respective slope degree occurring on the cell of terrain.

Inadequate cover - this class represents the land cover categories that are not presenting adequacy in relation to slope of cell. On the other hand, they still are not causing hazard and can be easily corrected.

Risks - it does respect to those areas where the land cover is strongly inadequate in relation the slope degree and easily might start problems (or they are started already) like soil erosion, landslides and/or soil loss fertility (for agricultural sites).

Urban settlements with terracing - represents the urban settlements located in waved or strongly waved relief classes. In order to avoid future problems in these areas, terracing is recommended (ALHEIROS et al., 2003).

Table 2 - Class distribution of each combined cell resulted from the intersection of land cover and slope data

Land Cover	Topographic Classes					
	Plane	Smooth	Waved	Strongly waved	Mountainous	Steep sloped
Pasture	2	2	2	3	4	4
RNV	2	2	2	2	2	2
Crops	2	2	2	3	3	4
Urban Area	2	2	5	5	4	1
Bare soil	4	4	4	4	4	1
Water bodies	1	1	1	1	1	1
Reforestation	2	2	2	3	3	4

Interpretation: 1 – bodies of water; 2 – adequate land cover; 3 – inadequate land cover; 4 – risks; 5 – urbanization with terracing.

Analysis of the vegetation fragmentation and the land cover in the buffer strip of the dam

Using the land cover map and through the *Reclass* command of Idrisi, it was elaborated a map containing only the “Remnant Natural Vegetation” class (considering the RNV class = 1 and all remaining land cover classes = 0). Using this new map, the number of fragments, as well as area of these fragments, was determined by the “Group” and “Area” commands of the Idrisi.

The land cover analysis in the buffer strip along the Itupararanga dam was carried out that, according to Brazilian law, must be at least 100 meters. The Buffer command of Idrisi was used to generate the range of 100 meters, which was overlayed with the land cover map through the Overlay command. From the resulting strip (land cover in the range of 100 meters), it was estimated the percentage of occurrence of each category of land cover.

RESULTS AND DISCUSSION

In figure 3 and table 3, it was shown the slope data of the city. It appears that the predominant class is “waved”, occurring in 36.6% of the study area, followed by the class “plane”, with 30.3% and then, “strongly waved” class, with 18.5% of occurrence. Comparatively, Silva et al. (2007) verified for the Sorocaba Municipality, neighbor of Votorantim and conurbed with this city, that the topography has a flatter surface, because there is a predominance of the plane class in 37.8% of the city area and strong waved class occurs in 7.0%, with a value a half of that observed for Votorantim. A notable difference between these two locations is due to the occurrence of the de São Francisco Hill, which occupies a greater proportion in Votorantim than in Sorocaba.

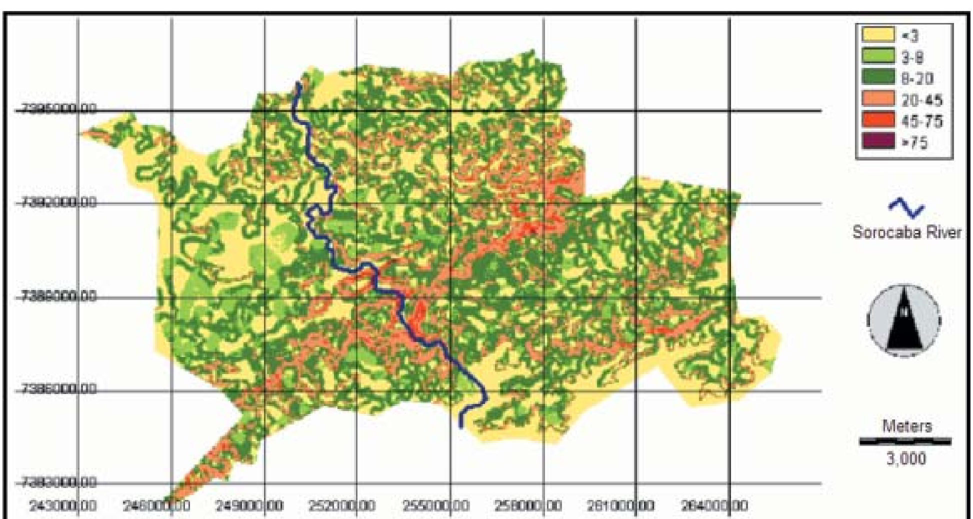

Figure 3 - Slope Map, in percentage, for the municipality of Votorantim - SP (UTM-23S)

Table 3 does not specifically describe the occurrence percentage of areas with slope level greater than 100% which, according to the Brazilian Forestry Code (Federal Law 4771/1965), is considered Area for Permanent Preservation (APP). However, due to the legal importance of this landscape in relation to the limitations of land-use, it was determined the value of 0.014% for the total study area.

Comparatively, this value is lower than the one found by Pinto et al. (2005) for the Ribeirão Santa Cruz watershed, located in Lavras - MG – Brazil (0.06%). These authors mention that this category of APP, even occupying a small area of the study area (hydrographic basin, rural properties or even a municipality), has significant importance for the conservation of soil and water of the basin. The authors mention that for this extremely steep region of the studied basin, most (70%) were occupied by pastures. In the case of Votorantim, it was verified that the region, located in a tiny polygon between the coordinates 252000-255000 E and 7380000-7382000 N (Figure 2), the land cover in 2003 was predominantly of Reforestation and with some patches of RNV.

Table 3 - Occurrence percentage of each slope class along the study area

LAND COVER CATEGORIES ⇓	SLOPE INTERVALS AND RELIEF CLASSES					
	< 3%	3 - 8	8 - 20	20 - 45	45 - 75	> 75%
	Plane	Smooth	Waved	Strongly waved	Mountainous	Steep sloped
Pasture	11.2	5.6	16.1	6.7	0.3	0.0
RNV	2.8	1.4	4.9	5.0	0.6	0.1
Crops	0.6	0.4	0.5	0.2	0.0	0.0
Urban Area	4.0	1.7	3.4	0.7	0.0	0.0
Exposed Soil	0.2	0.1	0.2	0.1	0.0	0.0
Bodies of Water	5.0	0.2	0.2	0.2	0.1	0.0
Reforestation	6.5	3.6	11.3	5.6	0.4	0.1
Total of relief classes	30.3	13.0	36.6	18.5	1.4	0.2

Source of intervals and interpretation of the slope classes: Santos et al. (2005).

The figure 4 and table 4 show that the predominant class of relation between relief x land cover is “adequate”, occurring in 76.2% of the study area. The class “inadequate land cover” occurs in 12.9% of the area, predominantly in the central region of the study area, precisely where the areas with greater slopes occur (see Figure 3). Fortunately, the “risk” class occurs in a small proportion (less than 1%) and urbanization of the area with terracing at 4.1%. The last value is a warning that indicates the need for supervision of works and the implementation of mitigation measures and disaster prevention, seeking solutions to counter the risks if the buildings are improperly implemented (ALHEIROS et al., 2003), specially during the rainy period.

This situation of greater or lower risk can be modified along the years, because the rains are seasonally irregular, with greater concentration in the months between December and February. The erosive potential of rains in Vororantim is considered medium-high (SILVA et al., 2006) and the cited period concentrates 57% of the annual erosive potential of the rains.

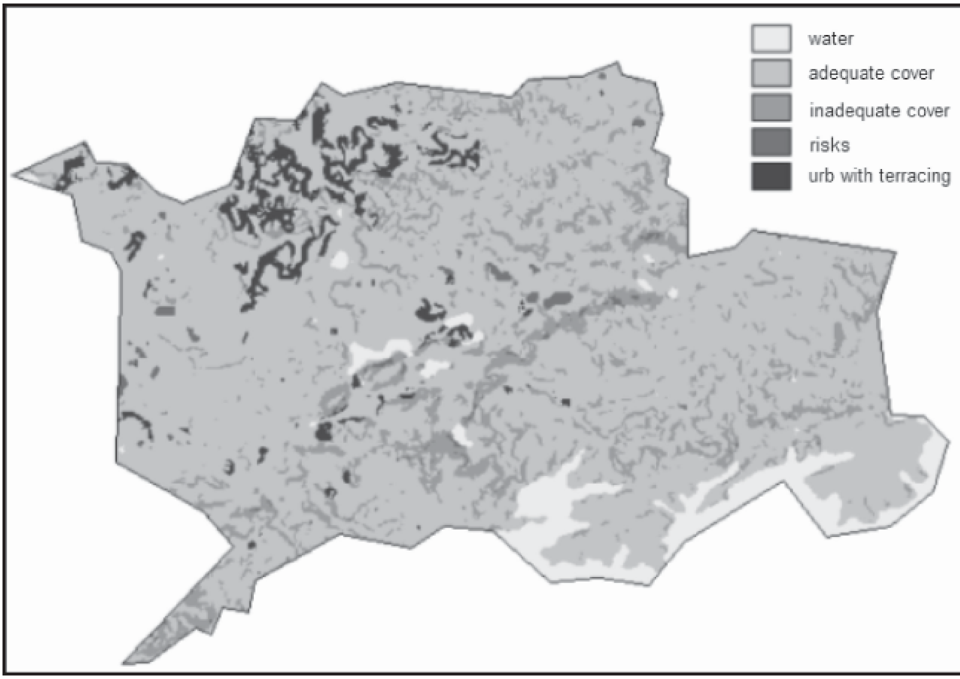

Figure 4 - Map showing the distribution of the interpretative classes resulted from the integration between the slope and land cover of Votorantim

Table 4 - Occurrence percentage of the interpretative classes resulted from the integration between the slope and land cover of Votorantim

Classes	% of occurrence
Water	5.8
Adequate Land Cover	76.2
Inadequate Land Cover	12.9
Risks	0.9
Urban with terracing	4.1

The categories of land cover that occurred in the buffer strip of the dam were distributed as: pasture: 27.0%; RNV: 57.6%; cultures: 0.4%; urbanization: 0.4%, and reforestation: 14.7 %. The other classes of land cover did not occur in the considered area. There is predominance of RNV class, followed by pasture. Instead of the fact that this value should be with 100% of RNV occurrence - according to Brazilian environmental legislation, fortunately the land cover categories that could be more degrading for water quality of the dam occur in a little expressive form, as crops and urbanization, which could respectively transport significant amounts of pesticides and sewage for the dam (REBOUÇAS et al., 1999). This also can be affirmed because in Brazilian territory pastures are not fertilized with mineral fertilizers.

This reflects in the water quality, which is considered in good / excellent quality and with adequate conditions of recreation activities, according to the CETESB's monitoring system of water quality (CETESB, 2008). Approximately 9 km^2 of the dam is located in the municipality of Votorantim and it represents one of the most important tourism points of the city, added with the 110 existing waterfalls in the municipality (PMVOT, 2008), which emphasizes the importance of preserving the land cover vegetation around the dam.

The 27.1 km^2 of RNV were distributed in 321 patches in the following order: 317 patches with an area smaller than 1 km^2 and 4 patches with an area between 1 and 5 km^2. This information is important and alarming for the conservation of the local wildlife, since it is well established that the number of species in an ecosystem is crucially dependent on the area of this ecosystem (SILVA, 2004b).

There is a critical probability that corresponds to a proportion of the landscape occupied by habitat in a bimodal landscape, formed only by portions considered as habitat and non-habitat for wildlife (non-habitat is all places whose land cover is not Remaining Natural Vegetation). This approach affirms that a landscape that is originally connected might suddenly become disconnected if the proportion habitat / non-habitat is smaller than 0.593. When the landscape suddenly changes from a state where there is percolation to a state where there is no percolation (METZGER; DÉCAMPS, 1997).

For this study, the observed value is 0.15, far smaller than the critical value. This means that there is a rare possibility to present any connection between the patches and reduced opportunities of percolation and maintenance of the wildlife in the original patterns of the region.

According to data collected here, it is possible to notice that the patches of Remnant Natural Vegetation are concentrated in the central region of the municipality (areas with strongly waved or mountainous relief) and also close to the dam. As none of them exceeds the size of 5 km^2, it is very difficult having good conditions for wildlife permanency and transition from a fragment to another, especially mammals.

The establishment of the connection of these fragments is extremely necessary to allow the transition of fauna between the patches and to avoid the emergence of metapopulations (Silva, 2004b). Attitudes such as the reforestation of riparian vegetation are important ways to restore the connection, once these ecosystems have an important function, among many others. One of them is serving as refuge and corridor for passage of fauna between the patches connected by this corridor (NAIMAN; DÉCAMPS, 1997).

CONCLUSIONS

The integrated analysis of the land cover and slope revealed adequate land cover for most of the study area. However, it was observed that the landscape was highly fragmented and the patches were poorly connected among themselves, showing urgency in reforestation activities in strategic locations in order to reestablish the percolation of the local fauna among the patches.

ACKNOWLEDGEMENTS

The authors thank FAPESP (grants 04/13096-7, 06/59809-0, 05/56234-6) for financial support.

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Recebido em setembro de 2008

Revisado em janeiro de 2009

Aceito em fevereiro de 2009