Geoprocessing for Urban Planning: Methodology for Decision Making in the Context of Social and Environmental Hazards in Urban Areas

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ABSTRACT

The Cabuçu de Baixo River drainage basin is emblematic of the recent evolution of many Brazilian cities. It is a basin under accelerated urbanization, still controllable, if well administered. This study created, as a contribution for Urban Planning and Public Administration, mapped positive assessments of environmental conditions (called "potentials"), and, similarly, negative mapped assessments generically called environmental "risks". The performed procedures represent an application of the Environmental Analysis computational methodology, contained in the program named VISTA/SAGA, which belongs to the GIS (Geographical Information System) SAGA/UFRJ, and was used for evaluation mapping and results validation. The conducted environmental evaluation produced a "Critical Areas" classification map, where lower grades (zero) are assigned to locations having the lower risks of floods and/or landslides occurrences. On the other hand, classes presenting higher grades indicate precarious settlements under imminent flooding or/and landslides risks. Geotopological analyses of available transposition areas, according to physical favorable factors and also distance from the critical places were conducted, to estimate the feasibility of settlement transpositions.

Keywords: Geoprocessing, environmental analysis, flooding risk, landslide risk, poor settlements, SAGA/UFRJ, Open Source Software, Geographical Information System, Public Policies, Urban Planning.

1. INTRODUCTION

The main phenomena related to natural disasters in Brazil are the landslides and floods, which are associated with intense and prolonged rainfall events, repeating every more severe rainy season. Flood processes produce great economic losses and significant impacts on public health, while landslides generate high number of fatalities [1].
According EM-DAT [2] data, 150 disasters were registered from 1900-2006, and 84% computed from the 70's, showing a considerable increase in recent decades. As a consequence, 8,183 deaths were accounted with a loss of, approximately, $10 billion. Illustration 1 shows the distribution for each kind of natural disasters in Brazil over a period of more than one hundred years.

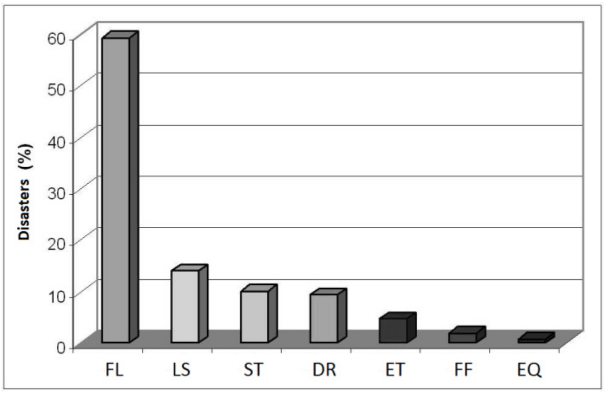

Illustration 1. Types of natural disasters in Brazil (1900-2006). Legend: FL - Flooding, LS - Landslides, ST - Storms, DR - Drought, ET - Extreme Temperature, FF - Forest Fire, EQ - Earthquake (EM-DAT [2])

This paper presents a methodology concerning socio-economic mapping elaboration and environmental assessments processing using the VISTA/SAGA program, part of a Geographical Information System named SAGA/UFRJ [13]. The Cabuçu de Baixo River Basin was taken as an experimental area for this application, which allows:
- Identification of possible critical areas (settlements located over imminent risk of floods and landslides occurrence), produced through overlay of risk assessments and Quality of Life maps;
- Identification of safe locations for settlements, near the critical areas.

The study case area: Cabuçu de Baixo River Basin - Features and Complexity
The Cabuçu de Baixo River Basin is a typical example of what has occurred in many Brazilian cities. It is under an accelerated urbanization process, but still under control, if well administered by their managers.
The urbanization process in this region was mainly located around Cabuçu river banks. It is estimated that proposed methodology application for this Environmental Assessment documentation, could fit as a model for many other small towns subjected to disordered and unplanned occupation processes, resulting in very serious environmental and social impacts, such as river basin pollution, rivers siltation, irregular housing construction, insecurity, instability in transport services, health and educational problems.
The north part of the basin has a relief of hills and mountains with steep slopes. Southward, the relief gradually gains

regularity until its end portion, at the floodplain of Tiete River. The rugged most prominent region is precisely the one with most recent irregular uses, mainly invasions and occupations, causing massive deforestation in geological risk areas. Inside the basin there are about 150 slums, 28 located in critical areas having geotechnical risks, in the northern portion of the basin [3].

The number of dwellings located in the risk areas has increased considerably in recent decades, without a plan to accommodate such urban growth. In response, the road system was being formed in order to support the population flow, originating diversified compositions for the street network, in response to the presence of the above mentioned mountainous terrain [4].

2. LITERATURE REVIEW

The use of terms derived from the colloquial usage, in research, naturally generates problems concerning their proposed scientific meaning. On the other hand, in environmental research, this is a common procedure. In principle, the terms used in research should be intrinsic, referring to an identifiable phenomenon, featuring simplicity and ease of use. Some words in common use may have these characteristics and are used in environmental ratings. This is the case of the terms "risk" and "potential", immediately associated with sites that have, respectively, difficulty or facilities for human habitation or for any other purpose (geological prospecting, for example). Some of the first questions arising in an environmental risk or potential discussion are are, of course, "Risk (or potential) of what?", "Where?" "How extense?". These questions denote the spatial character that can take the risk and potential terms. The attendance to these questions is enabled by the use of the terms and potential risks in texts and maps relating to environmental research that uses GIS [5]. When dealing with geo-referenced data, this subject may become, technically and scientifically relevant, for the importance that must be given to the possible incidence of hazards or the existence of a potential in a geographic areas.

The GIS (Geographical Information System), in summary, allows the reproduction of the convergence of factors typical of any environmental situation, identifying the specific locations where such convergences occur and thus characterizing them as places of risk or potential use. Factors considered may be physical, biotic and socio-economic, isolated or in combinations between them. The data for each factor can be shown up as a basic level of systematization, connected to the effort expended in their rankings. The systematization are notorious for generating errors, especially when used in data integration structures, as multiple criteria analysis, for example, of great use in environmental research. The data about dwellings will be judged against the estimated risk or potential, that is, considering the negative or positive occurrence chances of disasters, in relation to human occupation (obviously, this approach can, also, can be used in situations independent of man´s usage. The data convergence, in terms of occurrence place, defines the risk or potential spatial distribution of the estimates, considering the contribution of each factor.

MELO FILHO [6] presents a methodology for environmental risks (floods and landslides) and quality of life mapping in the *Canal do Mangue* Basin (city of Rio de Janeiro), integrating the human and physical environmental contributions. His analysis is structured in a decision tree [7], combining natural and historical factors, risks of human harmful activities, state basic infrastructure, the individual, socio-cultural and economic conditions as contributing factors for different levels of risk determination and quality of life at the studied region.

3. METHODOLOGY

The GIS methodology here adopted pertains to reference [7]. The occurrence of man-induced problems has considerable impact on the environment health. They occur within the basic dimensions of the physical world, and have taxonomic, territorial and time dimensions which must be considered in any investigations. This joint consideration allows learning about the past and present environmental conditions, and the creation of estimates about future situations. To fully understand phenomena, man, in a constant evolution process, develops concepts, methodologies and technical procedures for his learning, which allows support his environmental diagnoses. Based on a diagnosis, he can proceed to the prognosis, in which he makes suggestions to modify the conditions of resource use [7].

Formulation of the environmental analysis

The formulation of the weighted average is proposed in the environmental assessments, as expressed below:

$$A_{i,j} = \sum_{k=1}^{n} W_{ij(k)} \times G_{ij(k)}$$

where:

n → number of parameters (maps) used;

Ai,j → possibility of occurrence for the analyzed element (pixel i,j) of the matrix (map) result;

Wij (k) → parameter "k" relative contribution for the occurrence of the analyzed event;

Gij (k) → grade (or note), the second evaluator. Ranges of 00-10 (eleven classes) or 00-100 (101 classes) can be separately used to evaluate the possibility of occurrence of an event at a pixel location.

From this formulation can be made the following propositions, also according to [7]:

- Ai,j expresses the possibility of the occurrence of an event, or environmental entity, in correspondence to the convergent action of the environmental parameters at any point of the considered geographic area;
- the data involved in the evaluation can use an ordinal scale ranging between 0 and 10 or between 0 and 100, which encompass ranges of variation sufficient to consider the common oscillations of environmental estimates;
- weights standardization, restricted between the values 0 and 1, resulting in a weight value which defines the maximum ordinal value that any of the classes that map can assume. For example, assign a weight of 40% to the parameter "slope", in an analysis, means that the maximum that a certain class of this map can contribute for the possibility of occurrence of a event 4. on the scale of 0 to 10, and 40, on the scale of 0 to 100..

Decision Tree: Transpositions for Risk Areas

The whole process is modeled on a structure of representation called "Decision Tree" [7], which presents, step by step, each intermediate assessment needed to reach the final resulting map, named "Flood and landslides risks transpositions". Next are presented the elements of the used Decision Tree structure:

Socio-Economic Base

Presents the census data, obtained from the IBGE [9] (Illustration 4). They are the necessary elements for the generation of thematic maps that form the tree`s socio-economic base. The process is made possible, for this particular application, by using the module "Creating Thematic Maps", an application component of the program VISTA/SAGA. The selected socio-economic indicate the quality of the mapping. They were based on the Human Development Index (HDI) and Living Conditions Index (LCI), and address variables in the following dimensions:

- State and individual basic infrastructure: Households covered by piped general water network, household garbage collected; households connected to sewage systems.
- Social conditions and cultural heritage: average density of inhabitants per household, average educational level, literacy level.
- Income terms: Average income of households heads, responsible person earning less than one minimum wage.

Physical Database

It comprises the physical factors that directly influence the occurrence of the analyzed risks. For the application in the Cabuçu Basin were used Land Use, Slopes, Altimetry, Road Network Proximities and Drainage Proximity, Geomorphology and Geology maps.

Environmental Assessment

From the socio-economic and physical basis, a formulation was applied to the Environmental Assessment to obtain the maps of “Quality of Life/Slums,” “Environmental Hazards” (Flood Risk - FR and Landslides Risks - LR) and “Suitable Areas for Transpositions” (SAT).

Geotopological Analysis

According to [10], the GIS technology made possible, on a scale unimagined, to analyze an environmental Geotopology, i.e., a systematical and exhaustive investigate of the properties and positional relationships of events and entities represented in a geo-referenced database, thus helping the turning of data into information needed for decision support.

The identification of “Critical Areas” is a product of geotopological analysis. The map “Quality of Life” was overlayed upon the map “Environmental Hazards”. Processed by the VISTA/SAGA module “Combine Maps”, this overlay is able to reveal all combinations of classes between the two maps, thus being enabled to identify any selected joint occurrence of any two classes.

Finally, the maps of “Suitable Areas for Transpositions” are combined with maps of “Critical Areas”, and again, through the geotopological analysis, areas suitable for transpositions can be identified in terms of proximities and other dimensions of both the critical areas and the suitable ones (Illustration 6).

It is clear that each decision tree rectangle represents a digital mapping of a parameter of analysis or a performed environmental assessment. Inspection of this decision tree, as well as the subsequent partial ones, provides opportunities to present findings relevant concerning information origins:

- In the lower strata of the figure (the leaf nodes of the tree) contains the base maps containing environmental components that are critical to the analysis to be proceeded. They are the results of surveys and interpretations of the environmental reality of the Cabuçu River Basin. They may be combined through successive evaluation steps, each one aggregating related environmental parameters, in a manner similar to the one used in the other exemplified partial trees. This would avoid losses in the discriminatory power of de classificatory system used (weighted average).
- The maps of physical geography, used in the classes of risks of flooding and landslides, were produced as part of a research project named “Lower Cabuçu River Basin”. Conversion procedures were performed, changing maps in SHP digital format into the SAG/UFRJ raster format.
- Maps of environmental reality from the perspective of human geography, used in the estimates of infrastructural, social and income conditions, were generated from the census data produced by IBGE (Brazilian Geography and Statistical Institute) [9].
- It should be noted that the choice of parameters (maps), as well as weights and grades assignments used in this study were conducted according to the opinion of the researchers involved. It also should be noted that very seldom a pair of researchers has the complete domain of all environmental knowledge required by projects of this kind. Consequently, the recommended evaluation process is clearly declared here as requiring the use of research group evaluations, preferably obtained through the use of cooperative procedures like the Delphi process. Also consequently, the present paper may consider mainly devoted to show, under an organized form, peculiar aspects of the unorganized urban growth in Brazil. However, the authors trust it is, in the best of their knowledge, a valid source of detailed environmental information for the studied area.

Details of the factors discussed

Flood Risk - RE

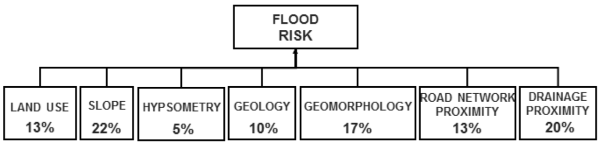

Illustration 2. Composition of Flood Risk Tree

The lower part of Figure 4 consists of digital maps shown above. From the combination of these seven parameters, weighted according to their postulated degree of importance, was generated the digital map Flood Risk. A similar case and conducted to generate the Landslide Hazards mapping.

Suitable Areas for Transpositions

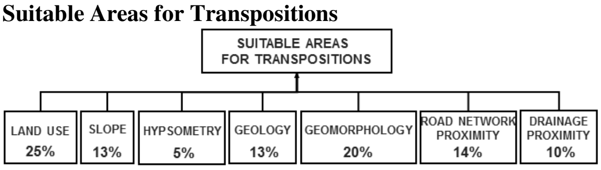

Illustration 3. Composition of the Tree of Areas Suitable for Transpositions

The evaluation processed with the tree above indicates the areas suitable for transpositions of slums.

Quality of Life (Slum Location)

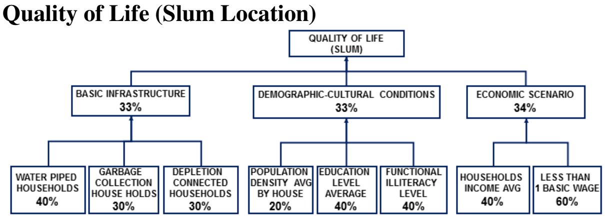

Illustration 4. Composition of the Tree of Life Quality (Slum Location – Based on Census Data)

Organization of Socio Economic Database

Immediately above are represented eight maps from census data [9]. The two right side maps show the conditions of the inhabitants in terms of income by census tracts (“average income of households accounted for” and “% of population with income below the poverty level”). These two maps generated by the evaluation, the map called “Terms of Income,” which depicts, in light of the parameters used, the economic condition of the population. Similarly, the left side maps “Households with piped water”, “Households with garbage collection” and

"Households connected to the sewer system," generated the map "Basic Infrastructure". Finally, the other three maps, "Average density of inhabitants per household", "Average level of education" and "level of illiteracy," make up the map "Demographic and cultural conditions."

These three maps ("Infrastructure", "Demographic and cultural conditions" and "Terms of Income"), generated the map "Quality of Life (Slum)", to be used later, during the execution of level of analysis for defining "critical areas".

The selection of socio-economic parameters was based on the Municipal Human Development Index (IDHM) and Living Conditions Index (ICV).

Trees in Critical Areas

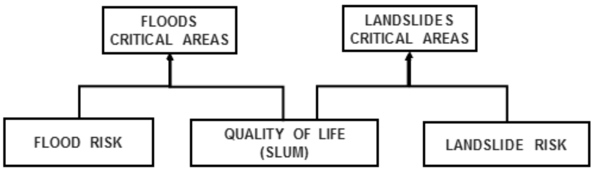

Illustration 5. Composition of Trees for Critical Areas and Flood Risk Landslides and Landslide Hazards

The first relationship is to identify areas in the risk maps (in this case only floods and movements of slopes) which coincide with places where slums occur or in which such settlements are likely to exist in the future.

Trees in Critical Areas to RDD and RE Transpositions and Possible

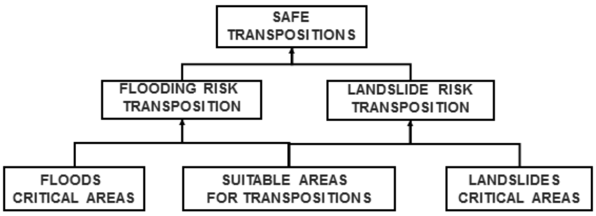

Illustration 6. Composition of the Tree of Critical Areas for RE and Possible RDD and Transpositions

The above tree diagram shows that it is possible to identify, with the additional support of a maximal distance beyond which slum removal cannot be performed, to avoid economic and social impacts the two critical areas are analyzed to identify slum areas to be transferred to suited areas found in the map "Suitable Areas for Transposition".

Another important product of this comparison between maps is the identification of slums in areas away from areas suitable for implementation. Other solutions for these settlements will have to be raised, one of them being the creation of solutions to improve the quality of life in the very place where the slums are established.

Organization of the physical database

The data used in this paper were produced by the project "Integrated Watershed Management in Urban Areas" [4]. This project is contained in the Environmental Atlas of São Paulo [1].

Territorial unit: census tracts

The territorial unit adopted for the analysis related to population is the census tract, as defined and identified by IBGE [9]. From the original data contained in spreadsheets, were obtained the geo-referenced database, expressed under a matrix structure, suitable for the analysis to be performed in the system SAGA/UFRJ.

The study area covers a total of 442 census tracts, which vary greatly in size. The areas of greatest concentration of human occupation have become more fragmented (in essence, the lower portion of the basin), while the northern sector, predominantly covered by native forest, show very low concentration of human features in a large portion of the territory.

The absence of socioeconomic data for census tracts located in the northern sector of the study area is due to the fact that these northern portion is classified as an Environmental Protection Areas (APA), and therefore not occupied by man. In data sheets derived from the Census (2000), available from the Brazilian Institute of Geography and Statistics, these sectors have null values for all fields of information [9]. This fact justifies the lack of results in the analysis of Quality of Life, based on census data from IBGE. It is the Serra da Cantareira, where in fact there was no case of human occupation.

4. PROCESSING AND RESULTS OF ENVIRONMENTAL ASSESSMENTS

As can be seen in the formulation of environmental analysis, the marks awarded to each class, are proportional to the probability of risks, expressed under an ordinal scale from 0 to 10 [7].

Map of Critical Areas for Landslides and Landslide Hazards

As input for this analysis, were used the geotopological maps "Quality of Life/Slums" and "Risks of Landslides and Landslide - RDD". The first map, shows five labels: very low, low, medium, high and very high risk. The second map shows four labels: low, medium, high and very high quality of life.

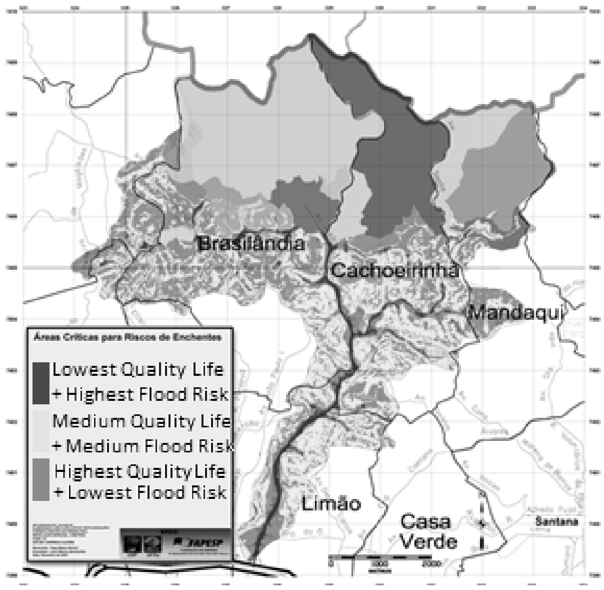

Illustration 7. Critical Areas for Landslides and Landslide Hazards

Considering the range of classes assigned to the resulting map, the following cases may be highlighted:

- Highest Quality of Life + Low Flood Risk: a combination of classes indicating, in the presently analyzed areas, a quality of life considered high, while the risks of landslides is considered low for these same locations.
- Average Quality of Life + Medium Risk Flood: represented by instances where the level of criticality

is considered medium, i.e., locations whose quality of life is considered medium and the risks are also present.

- Lower Quality of Life + Highest Risk of Flooding: represents the most important classes in this analysis. The quality of life is considered low, according to the IBGE classification, and, at the same time, is in areas of high risk of landslides. The classes “Highest Quality of Life + High Risk Flood,” “High Quality of Life + High Risk Flood” and “High Quality of Life + Most High Flood Risk” represents localities of high quality of life, but which also lie in areas of high risk. These, although not considered slums, should also be considered carefully because, regardless of social class, are located in high risk areas.

Areas Suitable for Transpositions

To assess the potential urbanization of the basin were taken into account:

Topographical factors: higher scores for steep slopes were assigned, since the risk of landslides increases with accentuation of the slopes.

Anthropogenic factors: The mapping of “Land Use and Land Cover” considers the type of current human occupation, assigning higher grades to areas without occupation, for example, the class “vague areas without vegetation.” The consideration of the class “near liquid surface”, was based on the assumption that the smaller the distance to the drainage network, the greater the risk of flooding. The vicinity of the road network was considered best, the closest locations of access roads, receiving higher grades.

Geological Factors: The geology and geomorphology analyze the types of rocks and landforms conducive to strong housing construction. Sandy, loamy, fertile valleys, peaks and spikes were considered not suitable for human occupation.

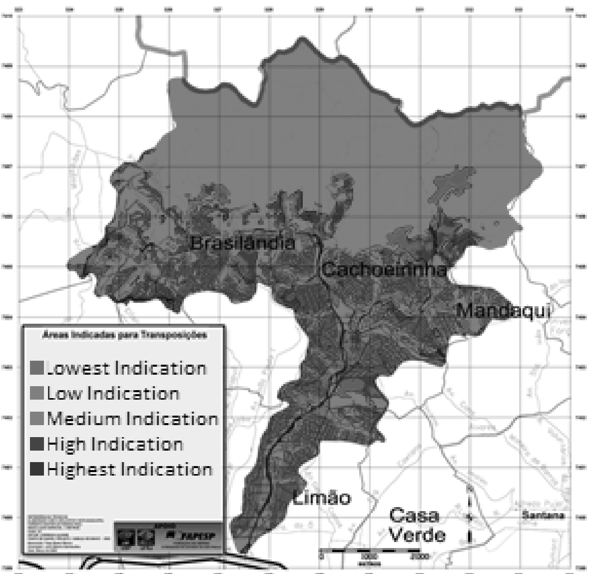

Illustration 8. Areas Suitable for Transpositions - AIT

Map “Transpositions due to Flood Risk”

The map “Transpositions due to Flood Risk” was obtained through the overlay of the “Map 2 - Areas Suitable for Transpositions - AIT” over the map “Flood Risk”. From the result of this superposition were identified areas suitable for transpositions (Map 2). Those are critical areas for floods, or where high risk of flooding, which coincide with areas of low quality of life. An analogous procedure was adopted for the preparation of the “Map 4 - Transpositions for Landslides and Landslide Risks.”

Through inspection of the map 4 is not only possible to identify the locations favorable to transposition, but also the occurrence of these areas close to residences located in critical areas. This condition greatly facilitates the relationship with the affected population, as these families will be displaced to areas considered safe and close to their socio-economic environment.

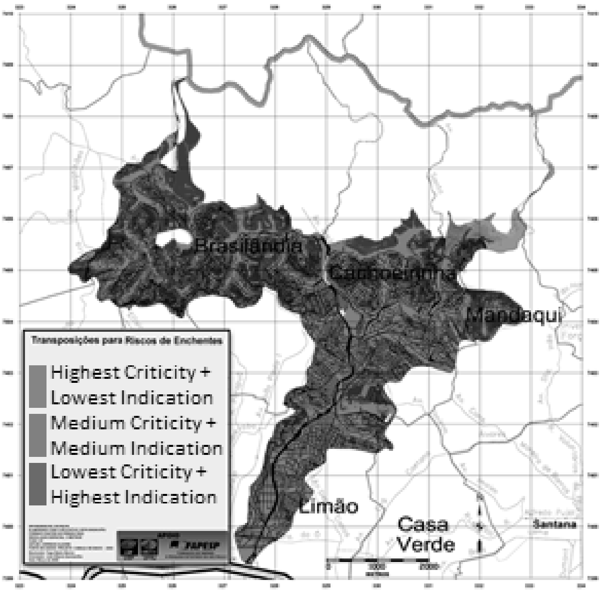

Illustration 9. Transpositions for Flood Risk

5. CONCLUSIONS

An environmental assessment pointed out the locations in the Low Cabuçu River Basin where urban sprawl should be avoided. These locations are subjected to high risks of flooding and landslides (potential conflicts). On the other hand, they are locations where urban expansion can be organized, based on detailed knowledge of the favorable and unfavorable environmental conditions (considering the three basic environmental characteristics: physical, biotic and socio-economic conditions). This possibility is clearly indicated on the maps presented in this text, created in accordance with the criteria presented in the methodology.

Complementary information can be obtained by mapping the occurrence of Slums, i.e;, low quality of life, according to the Human Development Index [11]. From this map geotopological analyses can be made through combination of maps. The program VISTA/SAGA was used in order to determine the occurrence of critical areas, or locations where they are found to occur together with slum conditions (low quality of life) over areas of high risk of flooding and landslides. The end result was presented in the “Map 1 - Critical Areas for Landslides and Landslide Risks.”

Finally, combining these last two mappings with the “Map 2 - Areas Suitable for Transpositions - AIT”, resulted in the mapping of areas for possible transpositions of slums. Through interpretation of the “Map 3 - Transpositions for Flood Risk” and “Map 4 - Transpositions for Landslides and Landslide Hazards,” could be identified surrounding areas safe for transposition (transposition indication for high and low risk of flooding , collapse and landslides), respecting a distance limit of the location of families found in critical areas. For slum areas which occur at high risk of flooding and landslides but without nearby areas suitable for relocation, it is suggested that investments are made to improve the infrastructure at these locations.

The attainment of the final maps of transpositions, given the risks analyzed, not only led to the arrival of the main objective initially proposed, but also proves the effectiveness of the application of Geoprocessing in oppressing environmental problems.

The objective of the present study is to show simple ways of acquisition of knowledge about environmental conditions prevailing in poor areas, generating diagnostic and prognostic elements for environmental decision support, aiming at improving the quality of life of the inhabitants.

In essence, was identified the potential use of the area, as a residential zone which can have the risks of harmful events minimized, within the local framework of threats and opportunities offered by the overall environment.

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