Methodology to analyze the environmental vulnerability of the population living in areas of flood and hillside sliding risks - an empirical analysis in the Onça river basin (metropolitan Region of Belo Horizonte, Brazil)

Glauco Umbelino[1], Cedeplar/UFMG/BRAZIL

Abstract

The main objective of this paper is to propose a methodology to analyze over time (from the 1991 census to the 2000 census) the environmental vulnerability of the population living in areas of flood and hillside sliding risks. Environmental vulnerability is considered here as the intersection between risk areas related to the physical environment (physical vulnerability), and socially and economically deprived population groups (social vulnerability). Considering the river basin as the ideal unit of analysis, this dissertation develops a conceptual and methodological approach and proposes an empirical analysis of environmental vulnerability in the Córrego do Onça river basin (located in the metropolitan Region of Belo Horizonte, Brazil), which has been subject to high population pressures for many decades. In order to accomplish these goals, it was created a Geographic Information System (GIS) which integrates environmental and census data (particularly census tracts) and allows analyzing the spatial distribution of physical (related to the physical environment), population and socioeconomic characteristics in the river basin. The results on physical characteristics were shown more reliable than the results on population and socioeconomic characteristics due to the problems of working with census tracts, which are relatively large units of analysis to investigate populations at risk and their characteristics. Even though, the results show that the population living in areas of higher vulnerability in the river basin faced improvements in basic household services (water provision, garbage and sewage treatment), income and education. Nonetheless, despite these improvements, there is still a large proportion of population living in risk areas, and those areas are still growing at high rates. The conclusion discusses how the methodology developed in this dissertation can be applied to other urban river basins and how it can be a useful tool to inform urban planning in areas of high environmental vulnerability.

Keywords: population, river basin, risk, vulnerability, environment.

1 - Introduction

The main objective of this paper is to propose a methodology to analyze over time (from the 1991 census to the 2000 census) the environmental vulnerability of the population living in areas of flood and hillside-sliding risks, according to what is specified in the Brazilian legislation. The text in this article is part of my Master's thesis (Umbelino, 2007). Considering the river basin as the ideal unit of analysis, this paper develops a conceptual and methodological approach and proposes an empirical analysis of environmental vulnerability in the Córrego do Onça river basin (located in the

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metropolitan Region of Belo Horizonte, Brazil), which has been subjected to high population pressures for many decades.

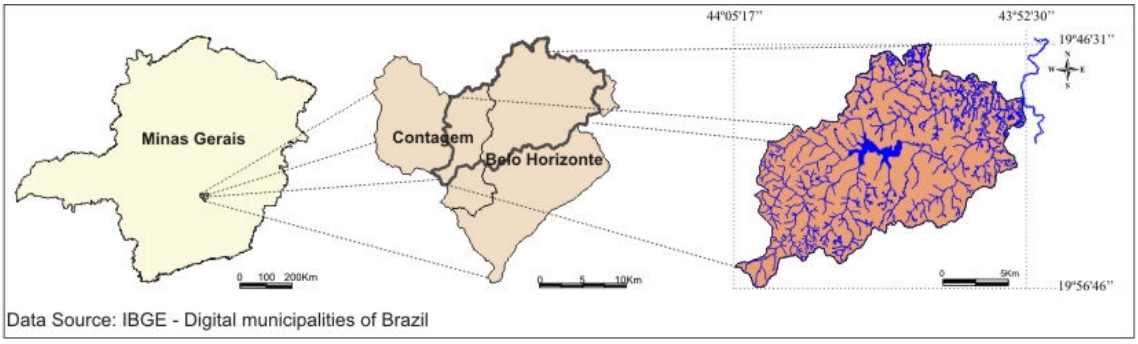
Over the last decades in Brazil, human interferences in nature were intensified, contributing to the increase of environmental and socio-economical problems in alarming levels. The urbanization advance on nature, in a disordered and segregated way, has been a factor that not only generated environmental problems, but produced social unsteadiness as well, involving poverty, risk and vulnerability in its several types (Martine, 1993; Smolka, 1993; Oliveira and Pinto, 2001).

The urbanization modifies all the landscape elements: the soil, the geomorphology, the vegetation, the fauna, the hydrography, the air and the climate. The indiscriminate occupation in the urban centres is one of the main causes of the cities environmental problems, and these places can be characterized by the elevated inequality in terms of income distribution, tenements, precarious households and reduced public services, particularly in the poorer population. It can be stated, therefore, that the elevated levels of urban poverty, social exclusion and environmental degradation have been characterizing the Brazilian urbanization (Braga, 2004; Carvalho and Braga, 2001; Monte-Mór et al, 2003).

As well as in other Metropolitan Areas of the country, the metropolitan Region of Belo Horizonte (RMBH) has presented an intense urbanization process starting in the 1950's. That fast urban growth, with its high rates of population growth and rural-urban migration in wide scale, defied the political and administrative competences, besides its capacity of providing the basic urban amenities, like water provision, sewage collection and treatment, and collection and adequate disposal of garbage. This situation became more serious due to the already existing poverty in the country (Hogan, 1999; Costa e Monte-Mór, 2002).

The analysed basin occupies an area of 212,5 km², representing 40,3% of the municipalities of Belo Horizonte and Contagem, together. In 2000, the basin had approximately 1.239.700 inhabitants, which corresponded to about 44,6% of the total population of Belo Horizonte and Contagem (2.776.543 inhabitants). It was verified that, despite the decreasing in the population growth through the last decades, the verified rates between 1991 and 2000 are still meaningful, as well as the number of dwellers in the tabulated areas. This basin was chosen due to the way in which it was occupied, as well as due to the great disorder that this basin is currently.

IMAGE 1- Location of the study area



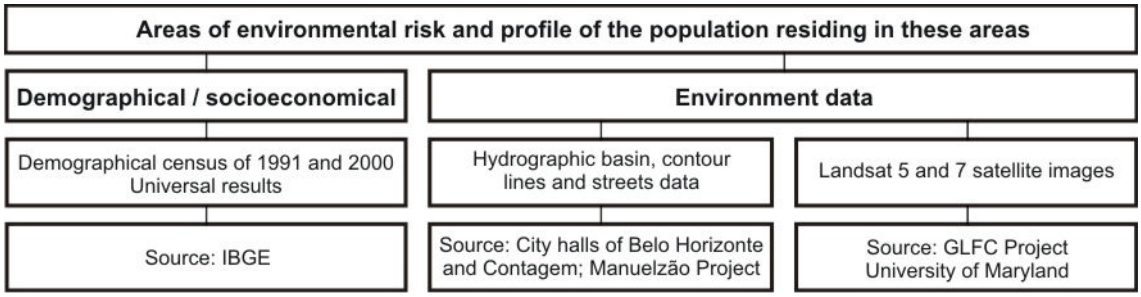
For analytical and methodological purposes, environmental vulnerability is considered here as the intersection between risk areas related to the physical environment (physical vulnerability), and socially and economically deprived population groups (social vulnerability) (Alves, 2006). The overlapping of these two factors is considered as an environmental vulnerability situation, since the environmental term comprehends the interaction between the natural and social components.

Therefore, this paper involves, within the theme "population and environment", an integration of theoretical, methodological and empirical aspects encompassing the discussions related to challenges that exist for the Brazilian urban planning, mainly the one related to the population which dwells in areas of environmental risk. As a theoretical reference, the thesis which generated this article proposes to use the hydrographical basin as a unit of analysis in environmental studies. Next, aspects of the relationships between population, environment and urbanization were discussed, within the study's context. Finally, a bibliographical revision was carried through, in the sense of seeking a definition for using the terms "risk" and "vulnerability" in this study (Umbelino, 2007).

2 - Data Source

It should be high-lighted that there are two distinct types of data sources used in this paper: the demographic and socio-economic data, which refer to the people which dwell in the area of study, and the physical and environmental data, referring to the characteristics of the natural environment, as shown in IMAGE 2.

IMAGE 2 – Source of the data used



The demographic data was taken from the smallest unit of Brazilian spatial analysis, the census sector. The data related to the physical characteristics of the space (Hydrographic basin, contour lines and distribution into streets) were obtained from Projeto Manuelzão, of UFMG, and the city halls of Belo Horizonte and Contagem. The satellite images were obtained from the project Global Land Cover Facility (GLCF) of the University of Maryland- USA.

3 – Legislação ambiental brasileira

Although the Brazilian experience has demonstrated that the existence of a law does not automatically imply its application and efficiency, the implementation of environmental laws in Brazil should be seen as an important breakthrough. Brazil has quite a sophisticated legislation concerning environmental themes, but most of the goals integrating these laws are not put into practice.

A great part of the environmental problems is more perceptible in large urban centers, where environmental degradation contributes to large social differences. Hence the importance of legal instruments, such as the City Hall Plan (Plano Diretor) and the Brazilian Water Law (Lei das Águas). Even though both are often not respected or even feasible, they are strong juridical instruments to be used so that environmental degradation in urban centers can be minimized. Along with this, it is important to emphasize that the above mentioned environmental preservation areas are not to be

occupied, since they posses an important role in protecting and maintaining the native flora and fauna, as well as in maintaining the water resources.
Minas Gerais is one of the Brazilian states with a great deal of water resources where, despite the strict State and Federal Legislations, many water courses are being extremely degraded because of inappropriate environmental handling, which leads to concerns as to the lack of water in a near future. From the several forms of environmental impacts capable of affecting the quantity and quality of the water, the impacts due to the urbanization process are remarkable. Cities constitute the most marking form of spatial tampering produced by mankind. In a hydrographical basin which goes through an urbanization process one can verify the most distinct types of impacts upon the physical environment, from polluting the water and reducing its availability, to changes in the pattern of the draining net (Lopes et al, 2003).
Despite these problems, the public policies being discussed in Brazil are directed towards the implantation of institutions which count on society's participation. Hence the need for change intended to be implanted through specific policies of water resources. These policies constitute a novelty in the normative field as they contemplate civil society as part of the decision-making process, along with the state and municipalities where the hydrographical basin is located. According to Carvalho and Braga (2000), it is through civil society participation that laws become more effective, are modified or are repealed.
The uncoordinated urban expansion that is occurring in the Onça River Basin, in Minas Gerais, is believed to be taking place in a way that controlling it would be extremely difficult, its regression would be practically impossible, apart from the legislation not specifying precisely how to handle these illegally occupied localities. The following paragraphs present a methodology based on the legislation considered in this study, in order to define what is meant by inappropriate areas for human occupation.

4 - Methodology

In order to accomplish these goals, a Geographic Information System (GIS) was created. The Geographic Information System (GIS) seeks to simulate the geographic spatial reality, allowing to store, to manipulate and to analyze geographical data in a computerized environment. This data represents objects and phenomena in which geographical localization is inherent to the information and is essential in order to investigate it. The GIS is a technology which, through computer programs such as MapInfo and ArcGIS, uses digital image processing and graphic computation resources to associate geographical information to conventional databases (Monmonier, 1997; Davis and Fonseca, 2001).
This system integrates environmental and census data (particularly census tracts) and allows analyzing the spatial distribution of physical (related to the physical environment), population and socioeconomic characteristics in the river basin. The methodology developed in this paper enabled the realization of the following goals:
- The census sectors of both analyzed periods were compatibilized so that a timely comparison of the demographic variables could be accomplished. An analysis of residential census variables and population's water provision, garbage collection, sewage system (physical components), income and level of study (socio-economic components) of the years of 1991 and 2000 was made, obtaining a profile of the residences environmental conditions for the dwelling population of this areas which are considered susceptible to the risks of flood and hillside sliding;

- Mapping of the urban stain expansion of the Onça river basin between 1989-2000. Complementarily, it was verified the localization of remaining not urbanized areas in the referred periods. With that information it is possible to interpret the behaviour of this urban stain in relation to the population growth occurred in the basin;
- Realization of the division of the basin's declivity, intending to identify and map the occupied areas which are not according with the Brazilian legislation (Lei federal 6.766/79) of urban land plotting and preservation of the water courses. Based on that information, a zoning of the basin was produced with identification of the risk areas subjected to flood and hillside sliding;
- Crossing of physical and socio-economic data to design a profile of the resident population in the areas that are not in accordance with the legislations (municipal and federal), and vulnerable to the mentioned risks.

Below are the maps of each of the previously described phases. The results show the limitations of working with census sectors as the unit of spatial analysis, as well as the existing compatibilization problems with census sectors from 1991 to 2000. It was also possible to verify the possibilities and limitations regarding the use of the GIS applied to Brazilian demography in small, mostly urban, areas; as well as the possibilities and limitations of the compatibilization of census sectors data with environmental data (Umbelino, 2007).

IMAGE 3 – Unified census sectors completely or partially inserted in the Onça river basin

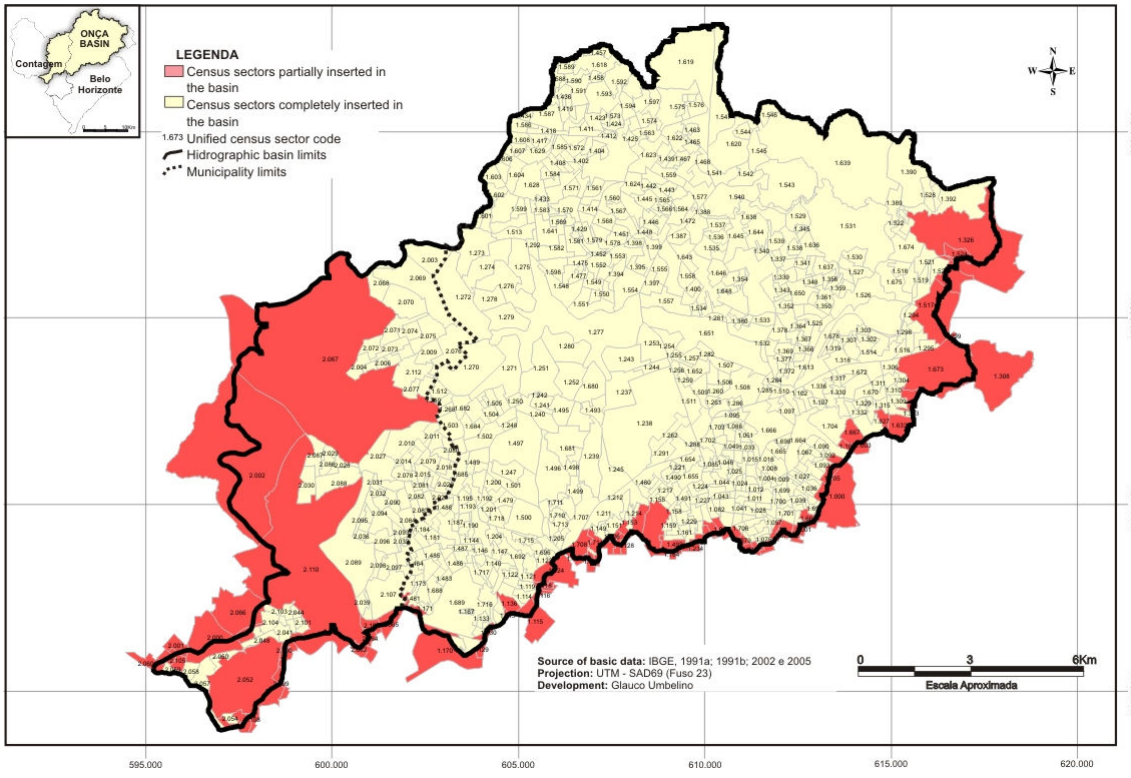


IMAGE 4 – Urban stain in the Onça river basin in 1989 and 2000

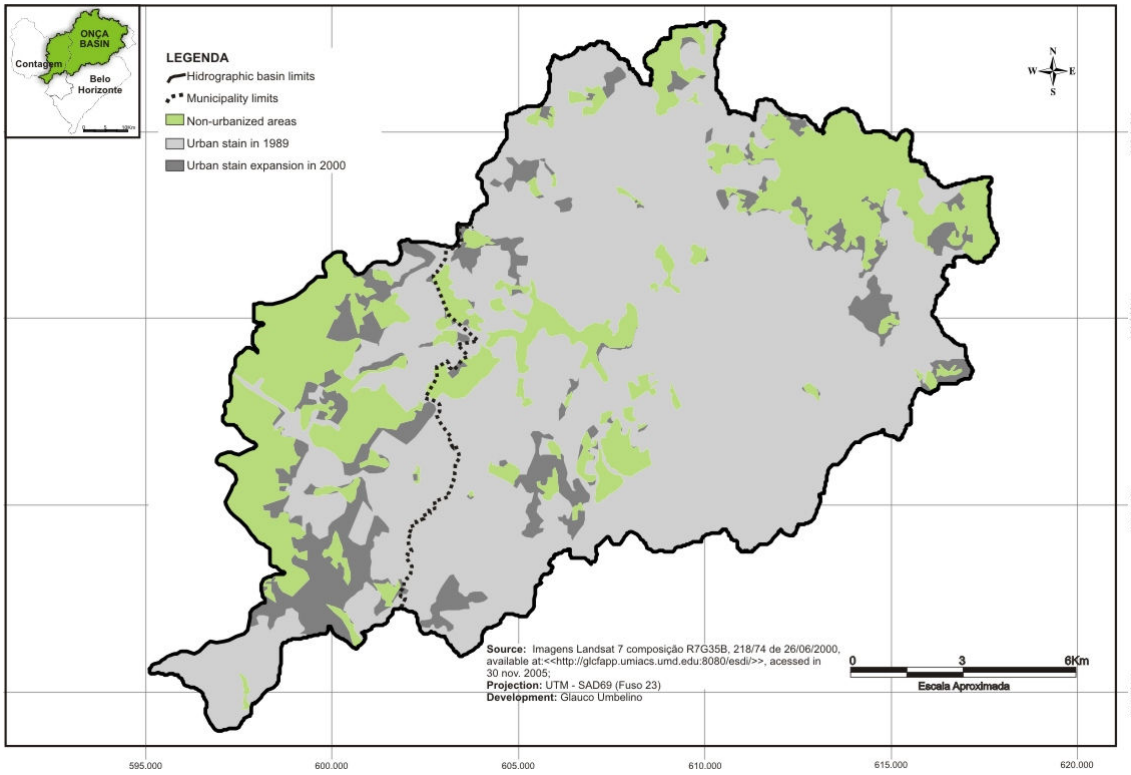


IMAGE 5 – Slope classification and Onça river basin's water courses' PPA delimitation

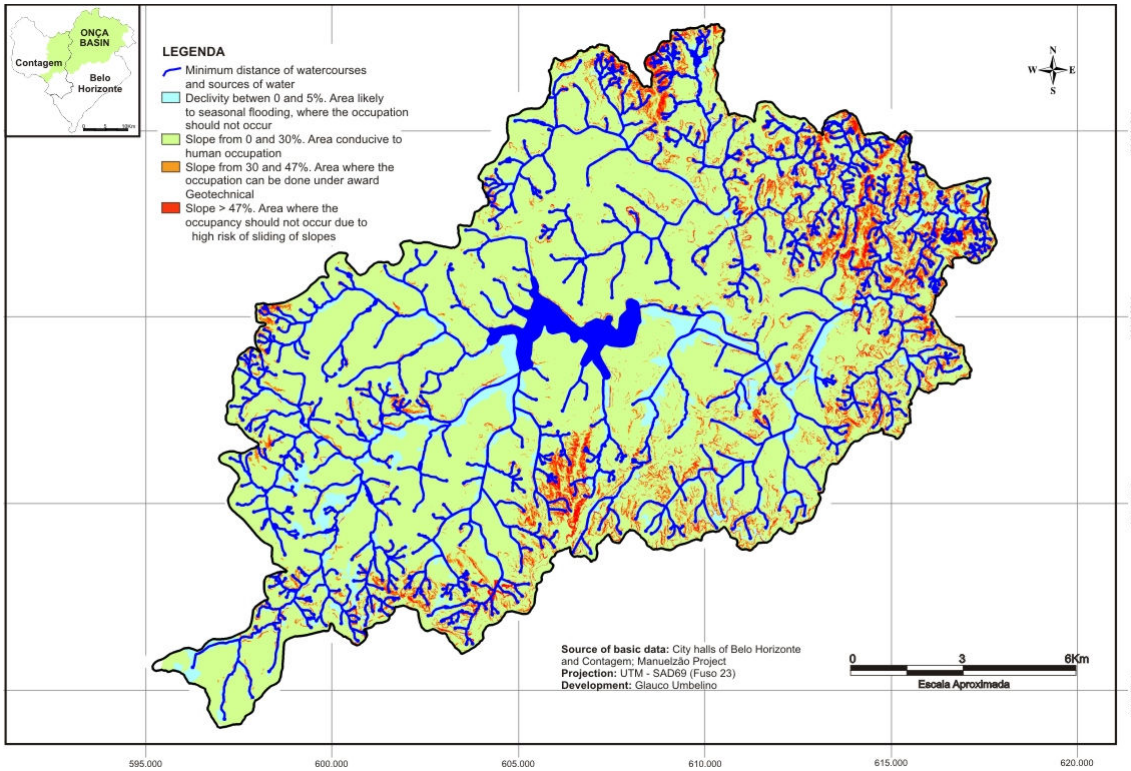


IMAGE 6 – Permanent Preservation Areas (PPA) within non-urbanized areas

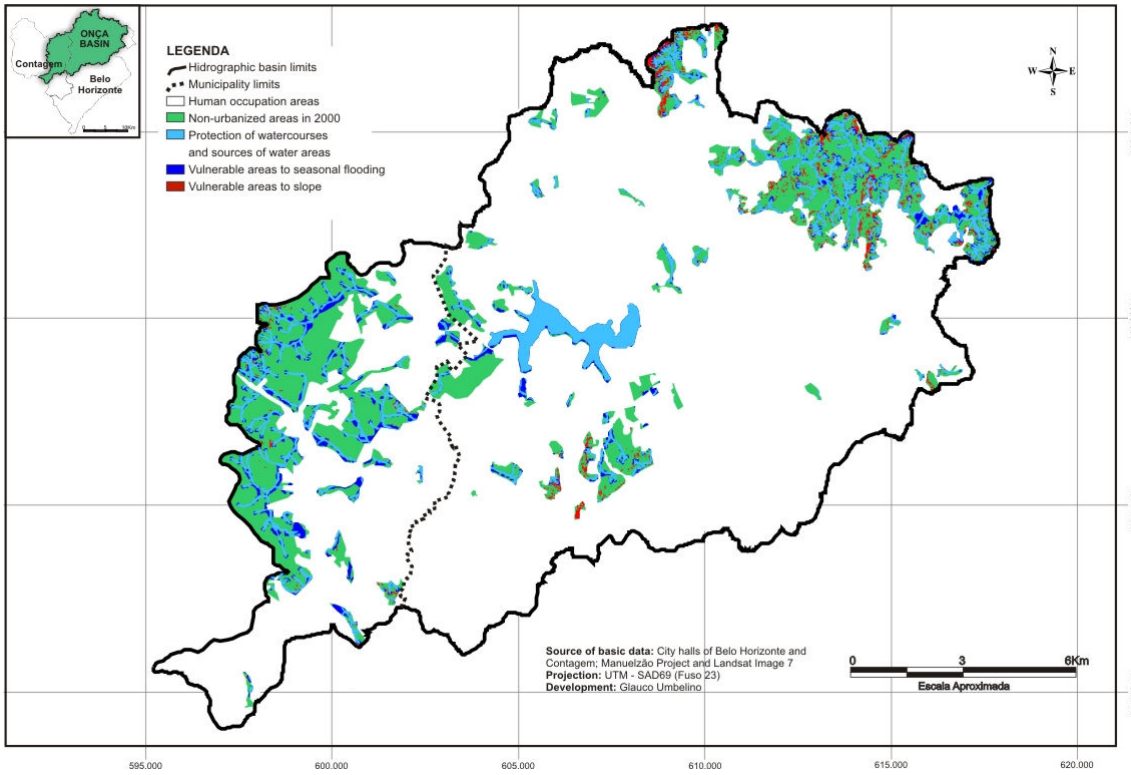


IMAGE 7 – Potential flooding and hillside sliding areas

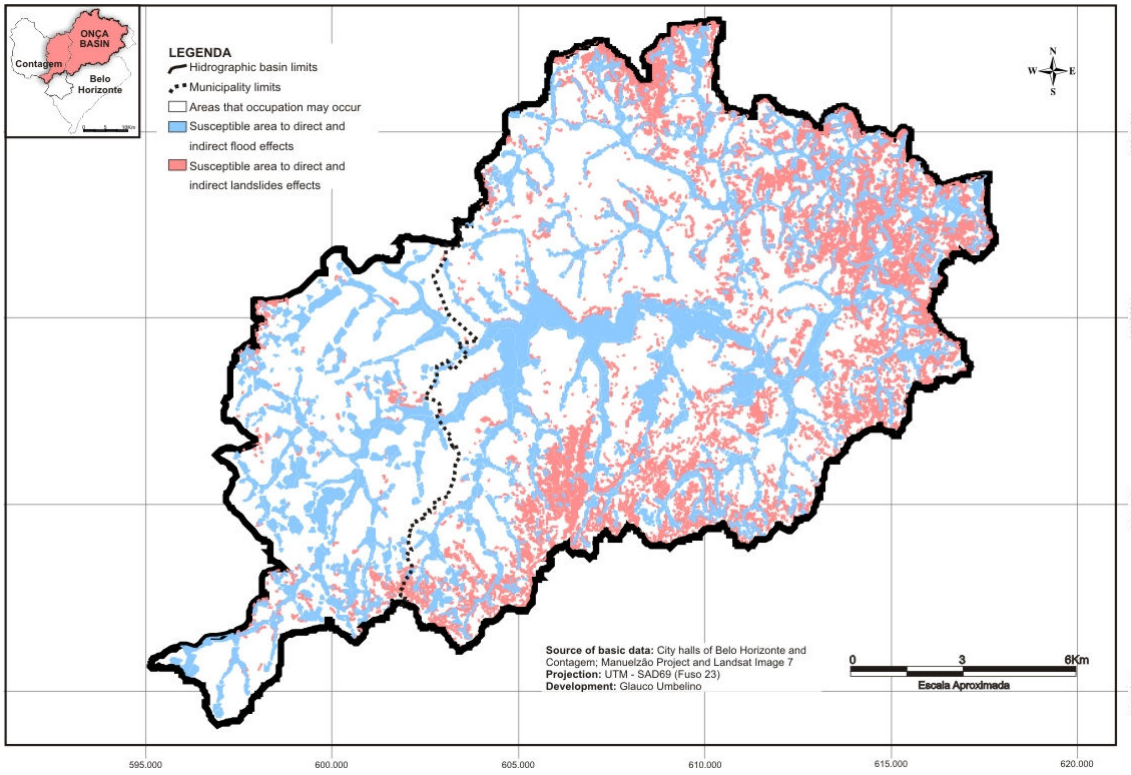
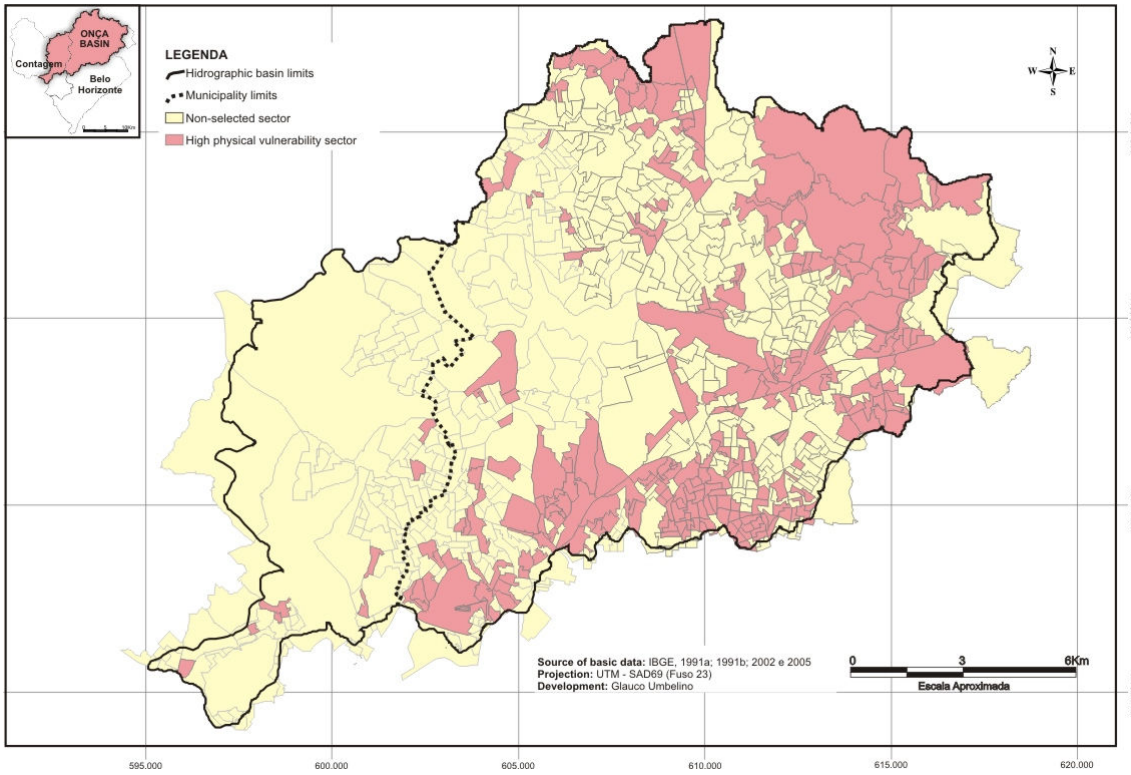


IMAGE 8 – High physical vulnerability census sectors



With the determined high physical vulnerability sectors, a profile analysis of the population residing in these areas was accomplished through the available variables in the universal microdata from 1991 and 2000, along with the comparison of the changes occurred in the period. One should note that the low income population in these sectors, apart from being a target of social and physical vulnerability, was also the most susceptible to environmental vulnerability.

All the used census variables did not suffer alterations in their definitions in these two censuses, facilitating the 1991 and 2000 comparisons. A time analysis of the variables concerning people's access to treated water, sewage net and garbage collection, as well as information on income and schooling.

5 - Results

The study area's population growth in the last few years, as well as the metropolitan Region of Belo Horizonte (RMBH) and Contagem, are shown on TABLE 1. The table shows that, despite the retardation occurred in the population growth over the last few decades, the rates between 1991 and 2000 are still meaningful, as well as the number of people residing in the charted areas.

TABLE 1 – Population and population Geometric Growth Rate in the RMBH from 1970-2000

Locality	Population				GGR		
	1970	1980	1991	2000	1970-80	1980-91	1991-2000
RMBH*	1.719.490	2.676.352	3.515.542	4.349.425	4,52	2,51	2,42
Belo Horizonte	1.235.030	1.780.839	2.020.161	2.238.526	3,73	1,15	1,16
Contagem	111.235	280.470	449.588	538.017	9,69	4,38	2,03
Onça basin**	-	-	1.029.781	1.239.684	-	-	2,10

Note: * The municipalities integrating the RMBH were retroprojected to 1970.
**** Estimated population.**
Basic data source: IBGE - Demographical Censuses from 1970 to 2000.

The decline of the population growth rates starting in 1990 in the RMBH was not verified in all the metropolitan area, since in some regions, such as the capital's outskirts, continue to expand in an accelerated manner. As a reason for this expansion one can point the intrametropolitan migration towards low income areas and towards private condominiums destined for the richer population (Costa, 2003; Matos et al, 2005).

When one observes TABLE 2, it is verified that between 1991 and 2000 the Onça river hydrographical basin's population grew at a yearly rate of 2.1%, whereas the housing grew at a yearly rate of 3.1%. This shows that, in the analyzed region, housing expansion has been more expressive than population expansion, since it incites an increase in the urban area and in the need for basic urban service access, since new housing demands more infrastructure.

TABLE 2 also shows the population growth occurred in the basin's 277 High Environmental Vulnerability and Other Sectors. It is possible to verify that in these High Vulnerability sectors, the population grew at slightly higher rates than in the Other Sectors, and that the most expressive growth rates occurred in the Permanent Private Housing (for which most of the results here charted will be interpreted). On the other hand, the lowest housing growth rate was verified in the High Environmental Vulnerability housings. This is partially explained by people who start their married life without moving into a new home, aside from many areas being difficult to occupy due to the environment's characteristics.

TABLE 2 – Population and housing information in the Onça river basin in 1990 and 2000

Variable	1991			2000		
	High environm. vulner. sectors	Other sectors	Total	High environm. vulner. sectors	Other sectors	Total
Total population	341.663	688.118	1.029.781	412.664	827.020	1.239.684
Perm. priv. housing pop.	338.810	684.426	1.023.236	410.199	822.688	1.232.887
Improvised priv. housing pop.	2.229	1.643	3.871	1.796	2.094	3.890
Collective housing pop.	625	2.049	2.674	669	2.238	2.907
GGR total pop. 1991-2000	-	-	-	2,14	2,08	2,10
GGR perm. priv. pop. 1991-2000	-	-	-	2,17	2,08	2,11
GGR improv. priv. pop. 1991-2000	-	-	-	-2,39	2,76	0,05
GGR col. hous. pop. 1991-2000	-	-	-	0,77	0,99	0,94
Housing Total	81.436	165.815	247.251	105.312	219.176	324.488
Priv. perm. housing	80.264	163.440	243.704	104.198	216.639	320.837
Priv. improv. housing	645	526	1.170	555	689	1.244
Priv. col. housing	528	1.849	2.376	559	1.848	2.407
GGR housing total 1991-2000	-	-	-	2,93	3,18	3,10
GGR perm. priv. housing 1991-2000	-	-	-	2,97	3,21	3,13
GGR improv. priv. hous. 1991-2000	-	-	-	-1,66	3,08	0,69
GGR col. housing 1991-2000	-	-	-	0,65	0,00	0,14

Note: Priv. hous. pop. - private housing population;
GGR - Geometric Growth Rate.
Basic data source: IBGE - Demographical Censuses of 1991 and 2000.

IMAGE 9 is presented below, with the population Geometric Growth Rate (GGR) occurred in each census sector compatibilized with the basin between 1991 and 2000. In an overall manner, the biggest sectors were those that presented the most growth, for these are the basin's least dense areas. Overlapped to the census sectors, the urban stain in the referred period is presented, which confirms that the horizontal expansion occurred preferentially, in the largest sectors, in a uniform manner throughout the basin. The east portion, belonging to the Contagem municipality, stands out, for it has been a target of several land divisions built over this period. Most of these land lots did not respect the Permanent Protection Areas (PPAs), since out of the 20.6km² that expanded the basin, approximately 1/3 (7km²) were legally protected.

Complementarily, IMAGES 10 and 11 show the population density overlapping the urban stain in 1991 and 2000, respectively. These last two maps show that there was a raise in these sectors' demographic density, since the largest densification occurred in the basin's less populated sectors, close to the urban stain's expansion areas.

Human occupation in the Onça river basin was not planned in order to preserve the sensitive areas, in geomorphologic and hydrographical terms, and the waterproofing of the soil (due to tar streets) brought on the superficial draining increase and infiltration areas reduction, which leads to frequent floods in the area. Practically all the basin's slums are located in steep areas which lack vegetation (with potential sliding risks), or along the water courses - these being the locations with the highest environmental vulnerability. Many constructions and streets built in the region did not respect, in their majority, the urban planning norms.

IMAGE 9 – Total population GGR and urban stain expansion in the Onça river basin between 1991 and 2000

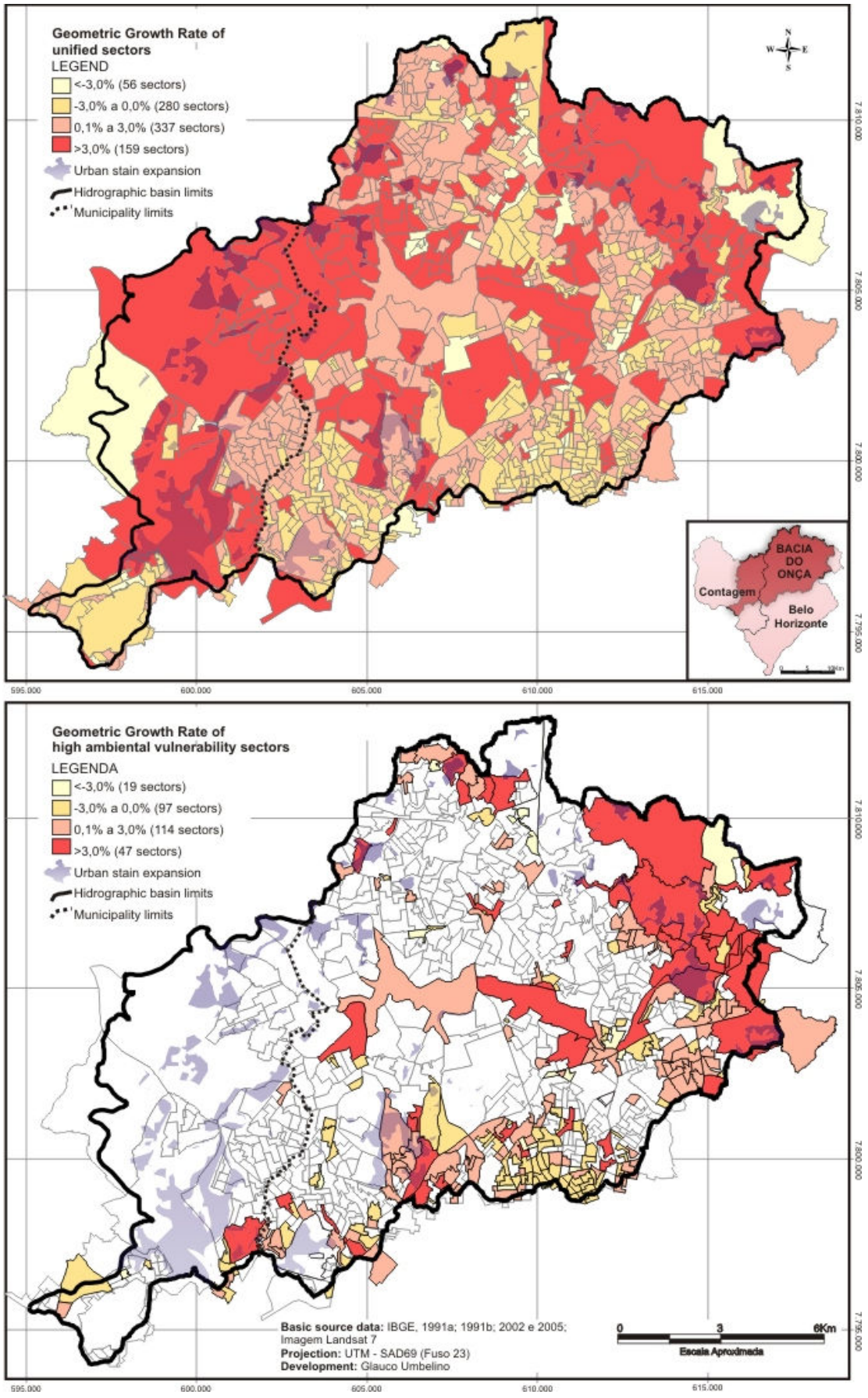


IMAGE 10 – Demographical density (inhab/km²) and non urbanized areas in the Onça river basin in 1991

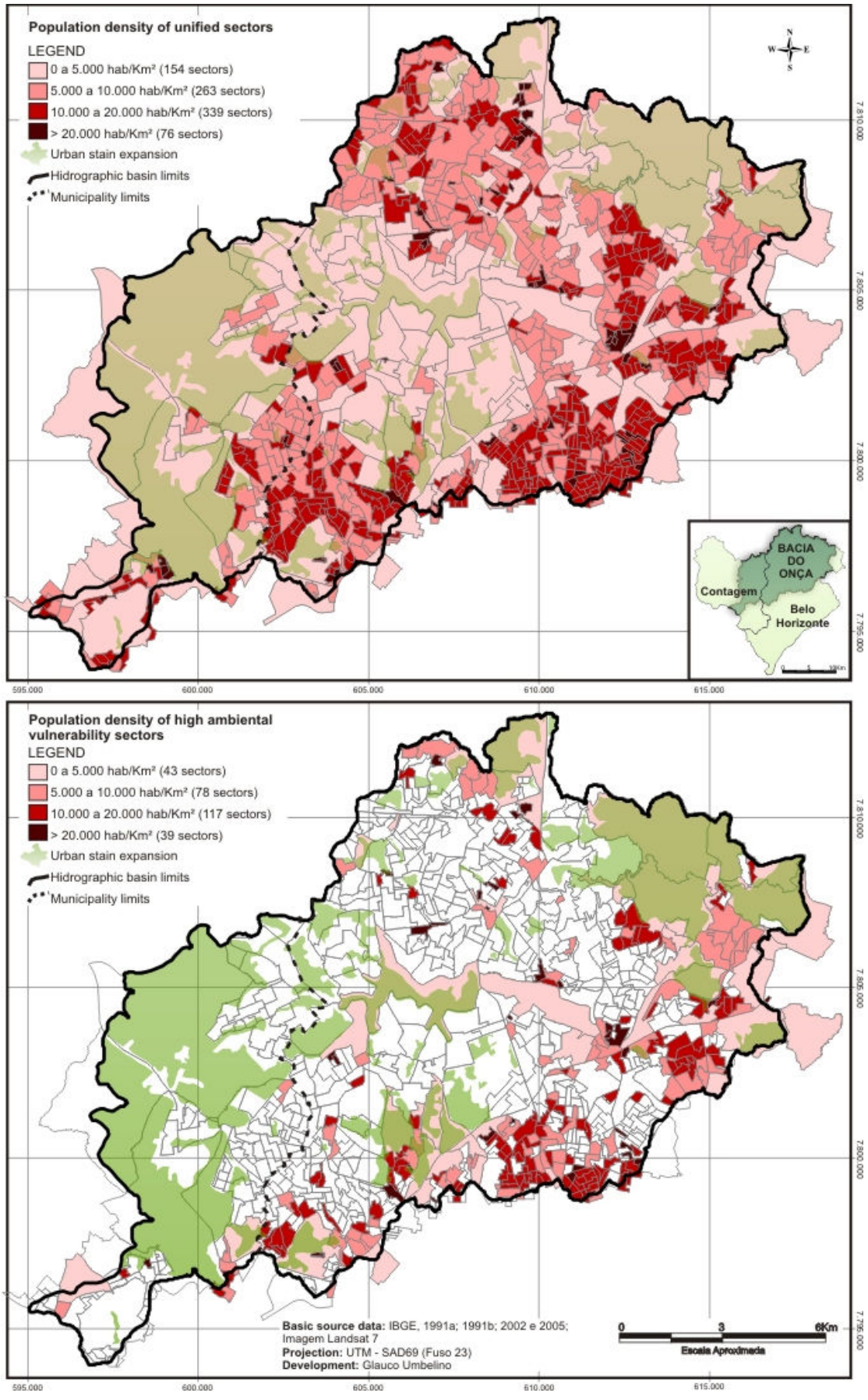
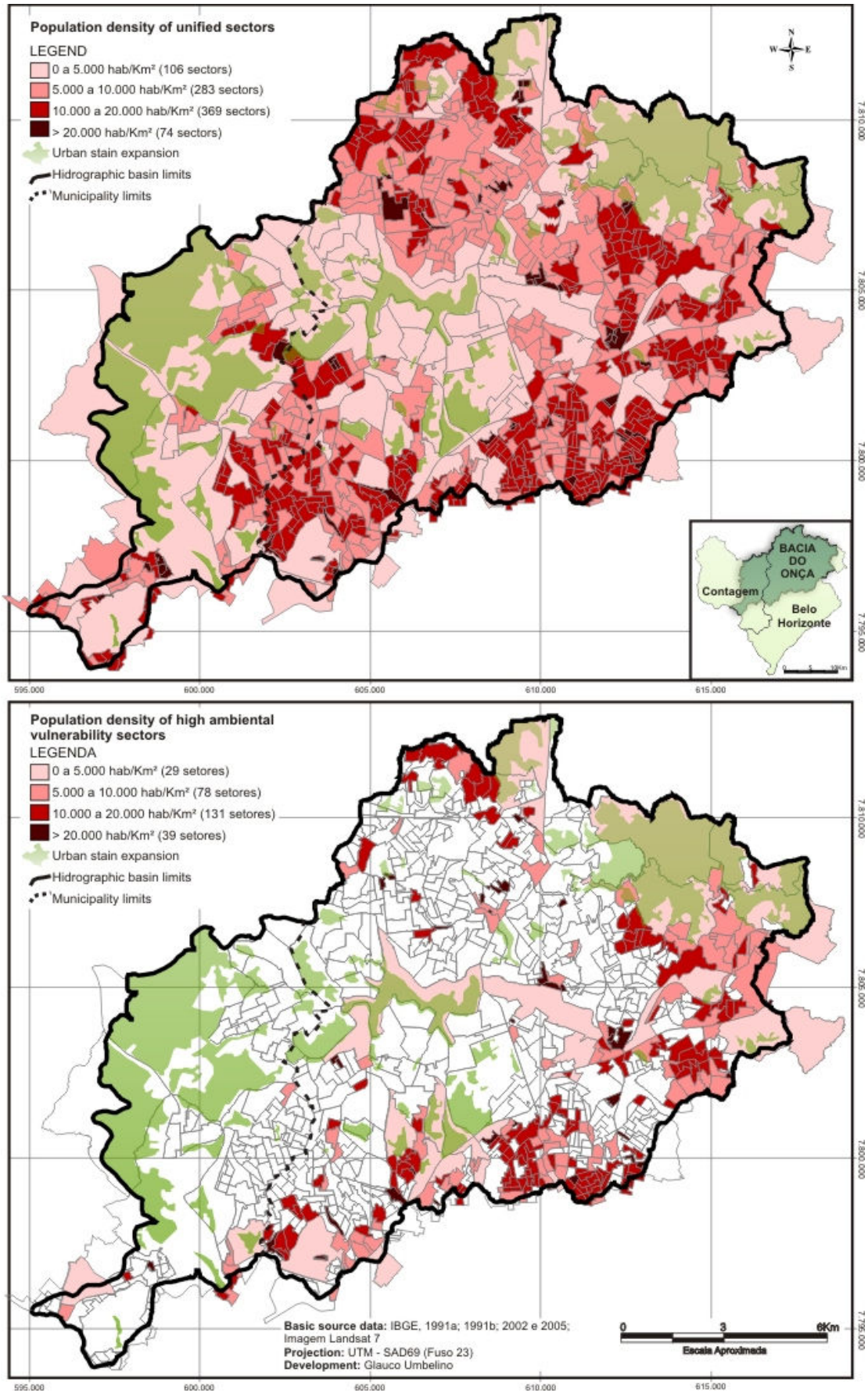


IMAGE 11 – Demographical density (inhab/km²) and non urbanized areas in the Onça river basin in 2000



Apart from the environmental impacts associated to the occupation of river sources, vegetation removal, accelerated erosion and soil accumulation in water courses, the disorganized occupation was not appropriately accompanied by the population's access to basic infrastructure in terms of sanitation (Lopes et al, 2003). The data which refers to the population not favored with the basic urban services refer to, in its majority, poorer families, many of which are composed by immigrants with hardly any professional qualifications and people with no permanent income. Most of these families live in slums and suburbs which are very environmentally vulnerable and that lack public services, often with areas that present high residential risks, such as floods and sliding. As Milton Santos said (1981), these slum areas are places high associated with misery, criminality, unemployment, homelessness and the lack of proper sanitation, among other factors.

Confirming the population growth data, the population density increased in the basin, at a rate of approximately 1000 inhabitants by km². As was expected, the most expressive population increase occurred in the most vulnerable sectors, where the density reached 6069 inhab/km². The urban stain increase confirms the horizontal expansion of 20.6km² in the basin, 6.9km² of these having expanded within the High Environmental Vulnerability sectors. On the other hand, the same area that suffered the urban stain increase logically implied a reduction on the non urbanized area. These non urbanized spaces represented, in 2000, 22.2% of the basin's total area, being 8.6% of these within the selected sectors.

Out of these non occupied 22.2%, 6.8% (14.4km²) are legally protected (as seen in IMAGE 6), as stated in the Federal Laws 6.766/79 and 10.257/2001, as well as Belo Horizonte City Laws 7.166/96 e 8.137/2000, which establish that slopes with high declivity, river sources and river bedsides are not to be occupied.

Moving on to interpreting the socioeconomic aspects of the population residing in the environmental risk areas, it was possible to verify that in what concerns education, the percentage of heads of houses and alphabetized population above 5 years of age increased between 1991 and 2000.

Using income variables (standardized in minimum wages (MW) in 1991 and 2000), it was observed that in the High Vulnerability sectors the heads of houses with an income that ranged between 15 and 20 MW tripled, whereas the number of heads of houses with an income higher than 20 MW doubled. This confirms the settlement of richer families in these sectors. It is important to remember that the population's purchasing power can minimize the sliding and flooding risks, since these families have enough resources to make safer constructions in these places, minimizing the effects of these natural risks within their homes.
On the other hand, heads of houses with an income up to ½ MW lowered from 6,081 to 599 heads of houses, which is assumed to be associated with an improvement in the quality of life of the neediest families between 1991 and 2000, who can now have further access to government transfers.
Moving on to an analysis of domestic physical components, one can verify that between 1991 and 2000 many improvements regarding the population's access to piped water occurred. The percentage of people consuming channeled water increased in 7.5%, with a total of 390,137 people accessing this service in 2000.

The rapid landscape transformations and soil, water and sewage pollution due to solid residues aggravated the population's low life quality situation and their vulnerability to diseases transmitted through contaminated water (Silva et al, 1995; Lopes et al, 2003). Several cases of diarrhea and other diseases are common in the areas where the population is obligated to live with and, sometimes, even consume this contaminated water. Contrasting with the elevated access to pipes water rates, the data showed that 1,164 people in 345 households still did not possess piped water, being susceptible to the mentioned risks.

Associated to the population's access to treated water is the access to adequate sanitary sewage. The improvements in this service were also expressive, since the percentage of people with access to the general sewage net increased in 13.4%. Although the drop in 2.8%, in the analyzed period, 7,654 people still deposited their sewage in an open ditch. Even more alarming is the information on sewage disposal in rivers, which doubled over the analyzed period, reaching 8.4% in 2000. If summed to the amount of people without access to proper sewage, and disposal in ditches and water courses, it is possible to observe that the rate increased from 38,637 to 41,717 people who reside in very unhealthy environments. This is an indicator that the present uniformity in the population's access to sewage services, in which a part of the population had improvements in the collection services, but, on the other hand, the population in high environmental vulnerability situations also increased.

Within the three basic urban services that were measured, garbage collection (municipal obligation) was that which presented the most meaningful improvements, increasing its attendance in 28%, that is, the percentage of people with garbage collection increased from 68.9% to 97.2%. As positive factors for minimizing environmental degradation, the quantity of people who burn their garbage decreased in 13.2%, and the quantity of buried garbage was practically extinct within these sectors. In 2000, despite the collected garbage, 6.473 people still disposed their garbage in empty lots or rivers, a fact that increases the flooding risks even further.

The analysis of the census variables demonstrates that population residing in the High Environmental Vulnerability sectors is closer to the universalization of the access to the three basic urban services. However, there are still plenty measures to be made, since apart from the universalization, it is also necessary to dispose properly of liquid and solid residues. Verifying the population's water quality should also be constant, as well as that of the basin's rivers.

6 -Conclusion

This paper proposes conceptual and methodological advances when it relates tasks involving natural and socio-demographic factors associated to the studies of risk and environmental vulnerability in various periods, in non-conventional areas of analysis, as the basins and the demographic intra-urban sectors. Thanks to the interaction between geography and demography in the studies about population in risk situations, a practical utilization of the concepts risk and vulnerability applied to the resident population of urbanized areas was possible, taking as a reference the applicable Brazilian legislation.

The results on physical characteristics were shown more reliable than the results on population and socioeconomic characteristics due to the problems of working with census tracts, which are relatively large units of analysis to investigate populations at risk and their characteristics. Even though, the results show that the population living in areas of higher vulnerability in the river basin faced improvements in basic household services (water provision, garbage and sewage treatment), income and education.

Nonetheless, despite these improvements, there is still a large proportion of population living in risk areas, and those areas are still growing at high rates.
The basin has shown itself as a unit of ideal analysis, to be a synthesis of the environmental reality of the region that is drained by it, assuming strategic importance in the planning and the managing of the urban territory policies.
Despite the complexity of the concepts of risk and vulnerability, of the difficulties of its operation and of partial or subjective aspects, it was possible to be verified that the essential of the methodology here proposed was the identification of how many, where, who, and where do people subjected to the analyzed risks live. Because it helps to answer these questions, papers like this are essential to generate parameters and criteria about the vulnerability of a determined population.
In that, the managing of public policies related to this area is more plausible of being applied to areas that are mainly urban. This methodological proposal may be used for urban planning, with contributions to the diminishing of the resident population in potential areas of flood and hillside sliding occurrences. This paper may also serve for a better comprehension of the environmental vulnerability that is present in those areas.
It is also important to be aware that the vulnerability is peculiar to each place, it is defined by physical and social conditions which shall be treated together. Likewise, the capacity of people to protect themselves against certain environmental risks is different, being the income regarded as the main conditioning factor of the protection.
It is known that there are many challenges to the completion of the methodology in here proposed, which does not unable its application to other basins under high demographic pressure and in different urban contexts. Some small adjusts may be made in order to adequate the proposal to the existing data of each analysed region.

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