USE OF SIMULATION FOR ASSESSMENT OF NATURAL DISASTER: A CASE STUDY OF FLOODING IN BELO HORIZONTE (BRAZIL)

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ABSTRACT

Many cities of the world suffer with the floods. When part of the network transport is interrupted by a flood, the congestion is the main problem observed. Solutions to this problem are necessary, considering the economic cost of congestion. This paper reports the results of the analysis of natural disasters using simulation through a case study for the floods that occur in Belo Horizonte (Brazil). With the simulation results, important parameters could be evaluated, such as travel time, distance traveled and average speed. Due to alternative routes designed to avoid the flooded areas, there was an 15.15% increase in the travelled distance and the travel time increase in 41.76%. The average speed of vehicles in the network decreased by 63.17%,. In this study, simulation was proven to be an important tool to the definition of routes to avoid flooded roads. and an important tool for assessing the impact of flooding in urban traffic. Cities such as Belo Horizonte (MG), with heavy traffic and frequent rains concentrated from November to March could benefit from simulation studies such as the one presented in this paper to identify strategies for emergency traffic operations during floods in the rivers crossing the city. Identify efficient strategies is important to reduce the economic and social damage caused by rain, which often leads to the loss of human life.

Keywords: impacts of floods; urban roads; traffic simulation..

INTRODUCTION

In the past, cities developed near rivers of medium and large size, in order to benefit from the facilities of water supply, river transportation, defense, among others (Bonatti, 2010). However with the rapid development of those cities, mainly observed in 20th Century, the flood plains were occupied disorderly.

A flood may be defined as a temporary covering for water in overlapping lands normal limits. Floods happen in small and large watersheds, estuaries and on slopes. Still, floods can be systematized according to the genesis of events such as floods caused by winter rains, summer storms conventional triggering floods, tides, urban sewage flooding, broken dams and floods caused by the operation of reservoirs. Each event may be classified by characteristics such as water depth, flow velocity, flow field and dynamic temporal and spatial (Schanze *et al.* 2006).

Yevjevich (1994) defines the three main types of floods as:

- Natural floods: any flooding that occurs in basins not occupied by human activities;
- Modified natural flooding: as the first, but in this case floods are modified by human intervention, such as flood mitigation;
- Disaster generated exclusively by men, including the group of floods caused by the collapse of structures such as dam break.

Floods can damage any traffic system. When part of the network is interrupted by a flood, many impacts can be observed in the characteristics of the vehicles flow, including congestion, the increased volume of traffic, reduced speed limits and increased travel time. For this reason, any effect on this network can be seen as a potential risk to the characteristics of traffic flow (Hossain and Davies, 2004).

There are several cases of flooding in Brazil and worldwide. Between 1985 and 1999, floods were responsible for 53% of deaths caused by natural disasters in the world, accounting for about 302,084 deaths. In the same period, the flood damage accounted for 29% of the damage caused by natural disasters, the equivalent of U.S. $ 275 billion (Berz, 2000 *apud* Mendes and Mendiondo, 2007). Latin America was the third region with the highest number of floods between 1973 and 2002, with a record 240 events, equivalent to 11.8% of total flooding the world in this period (International Strategy For Disaster Reduction, United Nations , 2003 *apud* Mendes and Mendiondo, 2007).

Some of them have significant impacts on vehicular traffic within a given urban area and other strongly affect the safety of the population and cities. In Brazil, between 2003 and 2008, more than half of the Brazilian cities suffered flooding due to the action of rain. The PNSB (2008) found that 34.4% of the total Brazilian cities have urban areas at risk and 56.8% of these flood areas are susceptible to greater risks in urban perimeters. Of the 5265 city who have some control over the rainwater - from gutters to underground galleries - 2696, or 51.3%, reported having suffered flooding during the period analyzed. Moreover, among the municipalities observed, 27.4% had one or more bottlenecks points, ie places where pipes are inadequate to drain the rain water, which may have caused or aggravated the floods (PNSB, 2008).

The same research found that 27.4% of the municipalities that have rainwater management reported not have had problems with flooding or bottlenecks in the drainage system in the last five years, 48.7% said the opposite. Of those who had reported problems with flooding, 60.7% said they had occupancy in urban areas flooded naturally by watercourses and 48.1% reported that they had irregular urban areas in flooding areas. In the North and Northeast of Brazil, the irregular occupation is the main aggravating factor, and, in the South and Southeast of Brazil, obstruction of watercourses is the aggravating factor to the floods. The Figure 1 shows the spatial distribution of municipalities that have problems flooding in urban areas and bottlenecks drainage system.

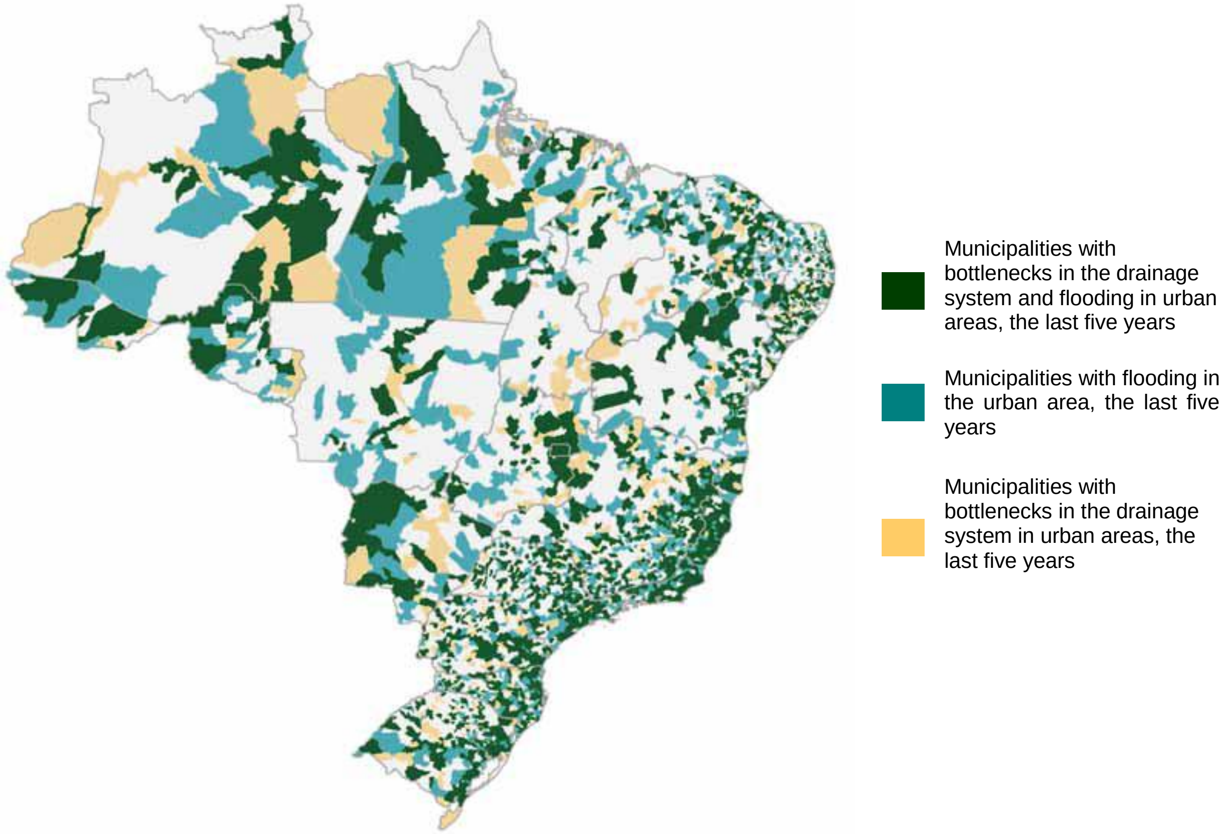

Figure 1 - Spatial distribution of municipalities that have problems flooding in urban areas and bottlenecks drainage system
Source: PNSB (2008)

In Brazil, the two biggest causes for floods are blocking the drainage system and the growth of irregular occupations in urban areas (BONATTI, 2010). In the Southeast region, an area that is the main problem of flooding from November to March, we have:

- 34.2% inappropriate scale of the project;

- 50.3% blockage of culverts and channels;
- 33.4% construction inadequate;
- 45.4% urbanization;
- 14.8% high water table;
- 19.8% deforestation;
- 39.6% inappropriate launching of solid waste.

Figure 01 shows the number of floods and victims by region, where one can observed the high incidence of rain, floods and hence the number of victims. In the Southeast, the highest incidence of disasters is in Minas Gerais State, but in Rio de Janeiro State is the greater incidence of floods and, consequently, a greater number of flood victims, followed by the Minas Gerais State.

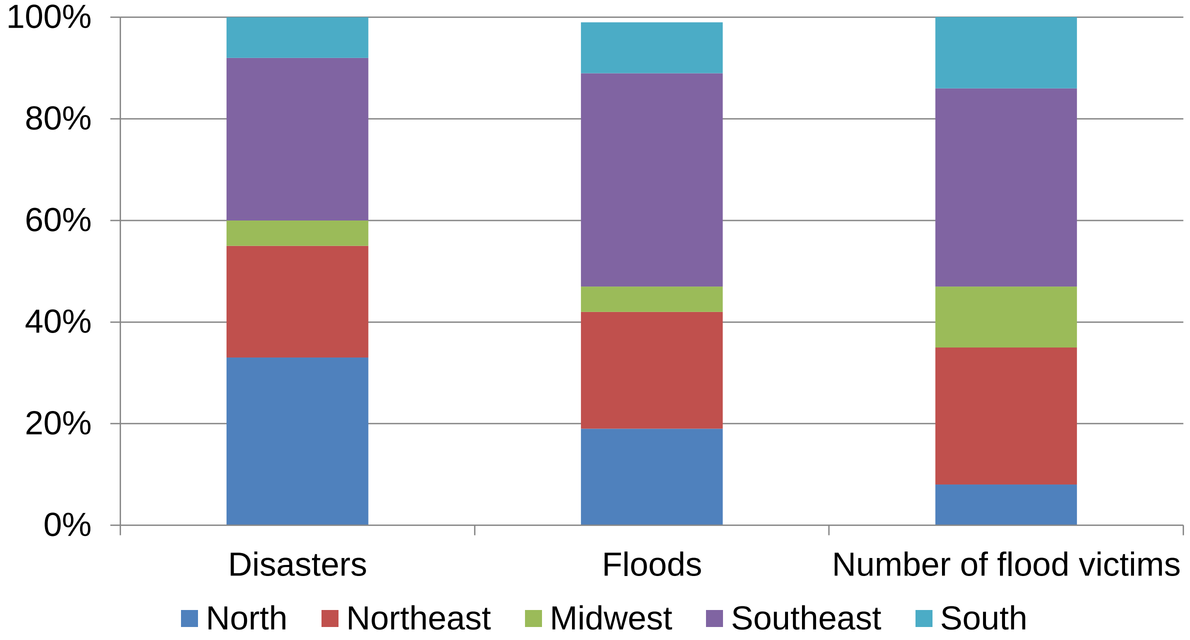

Figure 2 - Number of flood and victims by region in Brazil.
Source: Bonatti (2011)

The Belo Horizonte city, as well as other cities of Brazil, had a fast occupation without planning that would minimize the impact of the occupation on the hydrological cycle. Besides the urban dimension, Belo Horizonte has a distinct physical framework that generates different susceptibilities to natural flooding. To these aspects of use and occupation of land and local physical conditions are in addition to the lack of efficient urban planning policies, which are reflected today in the presence of numerous places susceptible to flooding, creating risks to life and to human activities in the city. These places were mapped by the Belo Horizonte Municipality (2009), as can be seen in Figure 3, which indicates that this phenomenon occurs throughout the city (Cajazeiro, 2012).

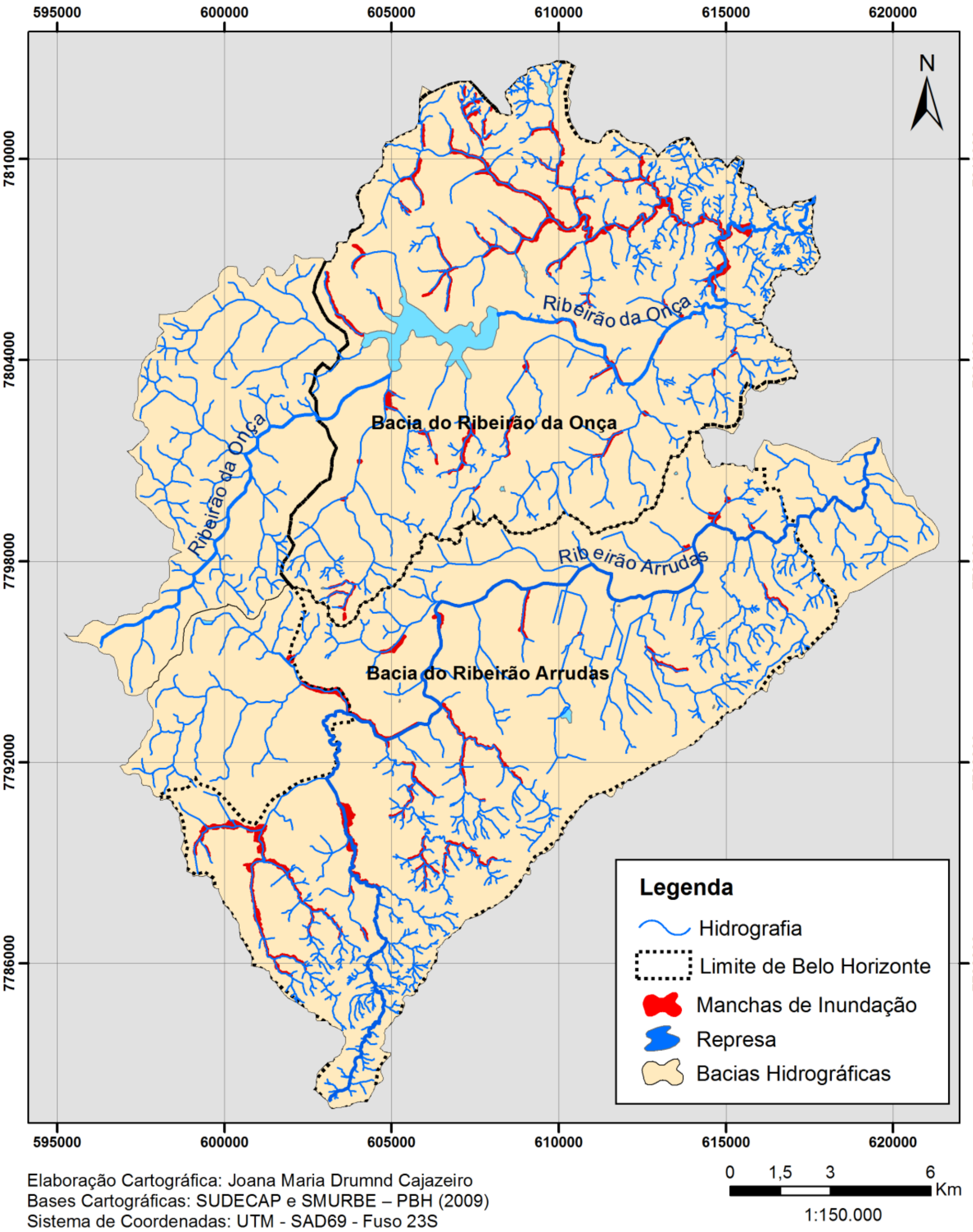

Figure 3 - Mapa de Manchas de inundação de Belo Horizonte.

Source: SUDECAP and SMURBE – PBH (2009) *apud* Cajazeiro (2012)

In the past five years, , on average, five floods happened in the Belo Horizonte city in average per year, concentrate between November and March. The Arrudas River is responsible for some of those flooding in the urban area, mainly in the Teresa Cristina Ave., Contorno Ave. and Andradas Ave.. On December 31th, 2009, the high incidence of rainfall caused the overflow of a small river, shown in Figure 4, which caused damages to the infrastructure at Teresa Cristina Ave.

Figure 4 - Rainfall in Teresa Cristina Avenue in 1987 (right) and 2009 (left)

In this context, this paper intends to present the results on the assessment of flood impacts on traffic, through a case study for of the influence area of Ribeirão Arrudas River. This paper presents indicators for floodings in Brazil, an introduction to microssimulation analysis and the results obtained from the simulation model used to analyze the problem. Finally, the conclusions are also presented.

THE FLOODS AND TRANSPORT

In the transportation sector, studies involving the modeling and evaluation of the impacts of the flood are still incipient. Oliveira *et al.* (2010) explain that the real reason the big floods in the city of Belo Horizonte is due to its topography, characterized by narrow valleys and steep slopes, soils with impervious surfaces that prevent good water infiltration.

According to Suarez *et al.* (2005) is important to assess the impacts of the flood on the transport system because: i) Some of the trips are canceled due to flooding at origin or destination; ii) Travel time will be much higher due to flooding. This can occur because drivers are forced to follow different routes from origin to destination, to avoid impassable roads, or as a result of traffic congestion. These disruptions have economic costs and can be expressed in terms of lost work days, lost sales or production losses (Suarez *et al*., 2005).

Dutta *et al.* (2003) developed a model to estimate losses related to flooding of a river. In this work, a model for estimation of losses was formulated based on relationships between flood parameters and characteristics of land use. From the model, estimated economic losses for land use based on simulated flood parameters obtained from the hydrologic model for a flood event. The interruption in the transport system was evaluated considering the traffic volume on each link in temporal scale, average speed, maximum traffic capacity on each link and the delay cost. This model was applied in Chiba (Japan), a medium-sized city and a river often overflows. For application, a flood event of 1996 was selected. The results indicated that there are two types of impacts to the transportation system: marginal costs and delays. The delay cost (552.11 million yen in damages) are much higher than marginal costs (1.05 million yen in damages), to the flood event of 1996. The impact of the traffic disruption on this flood was much smaller in comparison to urban flood damage, which is about 4% due to the duration of the flood be very short and only a few main pathways were affected by the flood.

Suarez *et al.* (2005) evaluated the impact of climate change on the performance of the transportation system through a case study in the Boston metro area. The methodology integrates projected changes in land use, demography and climate conditions in the modeling of urban transportation system, to explore the relative impacts of global warming on the system performance due to floods. The results show almost a doubling travel time. The authors indicate that these impacts are significant, but probably not enough to justify a major effort to adapt the physical infrastructure except for some important links.

Hossain and Davies (2004) developed a GIS system, given that floods and the transportation system has a strong spatial existence. This system can be classified into different levels of flood impact on the transport network and allows a qualitative assessment of these impacts. Furthermore, the system can visualize the impact of the flood on the characteristics of the traffic flow as a consequence of flooding.

Cançado (2009) explains the types of losses caused by flooding and the return time of the traffic flow on the road after flood, and shows the calculation of losses for environmental emissions. The author states that it is necessary to make a survey of local conditions to make a study of the flooding, considering information on weather conditions, periods of rainfall, drainage capacity of the soil water, flow capacity through, among other variables .

Oliveira *et al.* (2010) indicate the main elements for the realization of a traffic modeling, concluding that an information system traffic conditions is the main element for the calibration of the transport network. Oliveira *et al.* (2010) observe that the creation of new routes can be minimized economic problems, but not the environment. The authors studied the impact of flooding in the region's road system Venda Nova, in Belo Horizonte. Continuing the study, Barrouillet (2010) concludes that often is unfeasible to create new routes for urban roads affected by flooding, in which case, the required improvement of transportation infrastructure.

METHODOLOGY: TRAFFIC SIMULATION

A traffic simulation is a computational tool responsible for trying to solve complex and dynamic problem, often random in nature, through a modeling of road traffic from a particular region (PORTUGAL, 2005).

Every simulation requires the construction of a model with which the experiments are made. The model consists of a set of logical and mathematical relationships, usually described by a computer program and can be defined as an abstraction of a real system that will be used in order to forecast or control (PORTUGAL, 2005). To develop a traffic simulation project follows the roadmap presented in Figure 05.

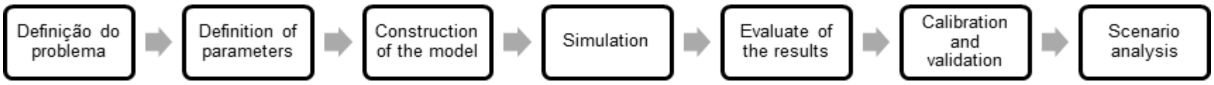

Figura 5: Roadmap to traffic simulation project
Source: AZEVEDO, (2000, p. 60).

Among the advantages of using the simulation are: evaluating a real long period of time in seconds or minutes simulation, understand the system under analysis, the simulation does not disrupt the activities of the real system, being able to analyze temporal conditions (AZEVEDO, 2000). Among the disadvantages of using this computational tool stands out: the time spent in the construction, calibration and validation of a model and simulation, and hardware required to analyze complex systems (AZEVEDO, 2000).

DESCRIPTION OF THE STUDY AREA

The study area comprises the Arrudas River at the top of Figure 6, when it overflows, reaches the main avenues in the Central region of Belo Horizonte. The central area of Belo Horizonte is the hub of trade and services, concentrating the main commercial and financial activities, and also covers the noble area of the city gathering most of historical, architectural and cultural facilities. The resident population central region is, nearly, 261,000 habitants, with an area of 32.49 km² and a population density of 8,019 inhabitants/km² (PBH, 2010).

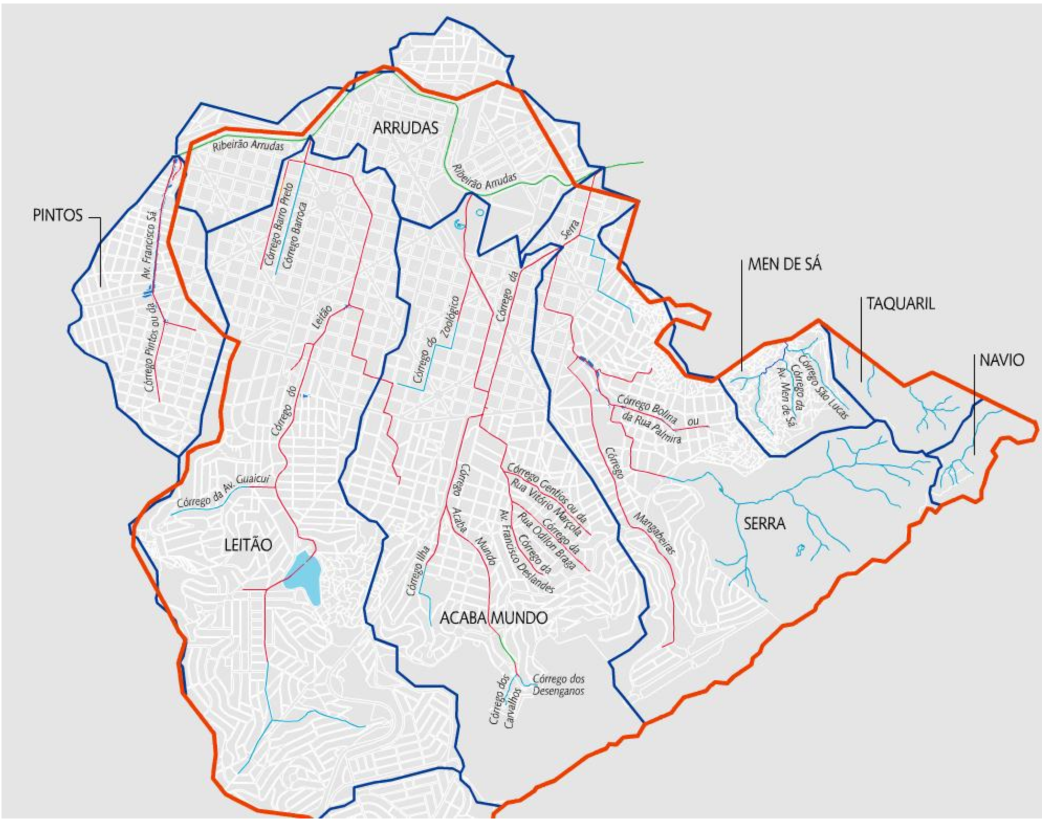

Figure 6: Study area

In this region, according to the Municipality of Belo Horizonte (2010), the traffic peak hours starts at 7am in the morning, and between 17h-18h. In average, 78,62% of traffic is composed by private cars in this region (Figure 7).

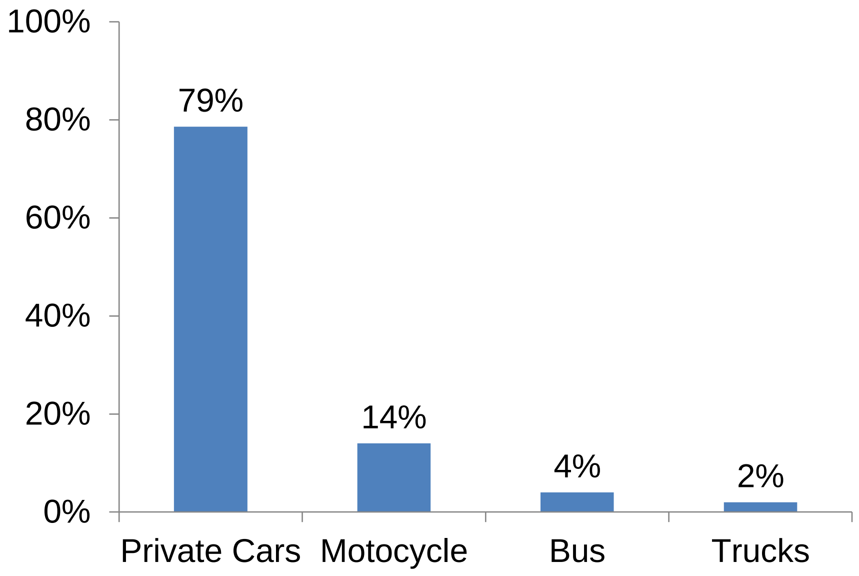

Figure 7 – Traffic Flow in study area

RESULTS AND CONCLUSIONS

Two scenarios were simulated to assess the impacts of the Arrudas River flooding in the study area: a scenario without the overflow of the river, and consequently without flooding and another with river overflow and hence disruption of urban roads due to flooding of the study area.

Of the simulation results were analyzed the following parameters of the transport network for each vehicle category: number of vehicles, travel time in hours, total distance in kilometers traveled, total delay in hours, average speed in km/h, average time delay in seconds and average number of stops.

The Figure 8 shows the Average percentage increase in the evaluated parameters with the overflow of the Arrudas River, in the study area. It is important to note that the study area, there are few alternative routes for urban roads affected by flooding, making the impact on travel time and delay meaningful. Furthermore, it is noteworthy that a scenario was simulated with a time of 1 hour flood, and the urban ways were closed to traffic for about 30 minutes, according to the results of the hydrological modeling.

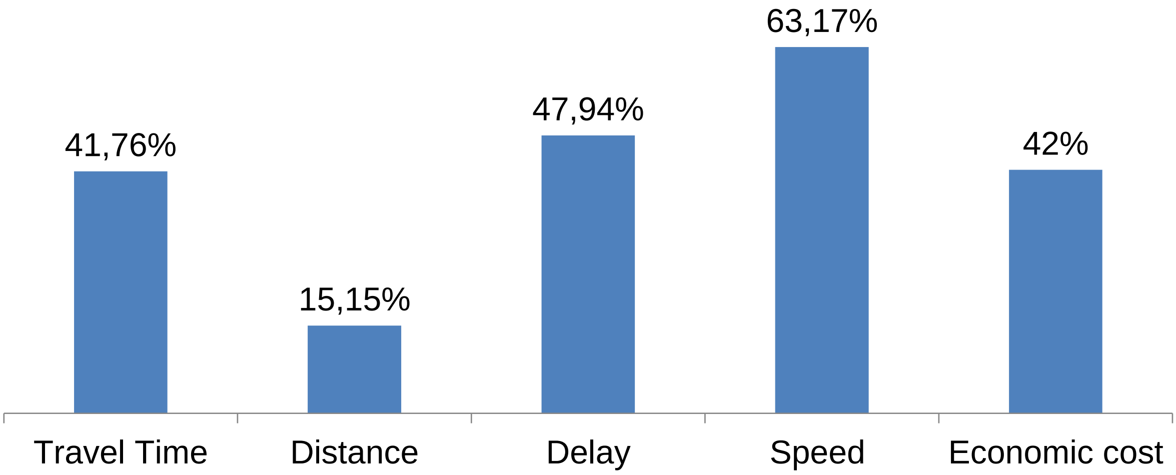

Figure 8 – Average percentage increase in the evaluated parameters with the overflow of the Arrudas River, in the study area

For the scenario in flood analysis, the impact was $ 370 thousand dollars, considering the methodology proposed by Cançado (2009), which could be reversed at improving transportation infrastructure, thereby reducing the impacts caused by flooding in the area study.

Furthermore, the results indicate that the traffic simulation is an important tool for the analysis and planning of alternative solutions that minimize the impacts of flooding in urban areas.

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