Landslide Risk Mapping as Risk Management Tool

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Abstract

In São Paulo state 260 cities were mapped by several instruments such as the Municipal Risk Reduction Plan (PMRR), landslide inventory risk map, landslide risk evaluation map. The municipality of Arujá can be cited as a good example of good practice in landslide risk management. This paper present the results of the mapping carried out in the municipality in 2012 and 2016. In the PMRR made in 2012, 14 risk areas indicated were mapped. These areas were subdivided in risk sectors: nineteen with landslide risk, seven with river margin erosion and seven with flooding , making 33 sectors. Among the landslides risk sectors 02 were classified as very high risk, 05 as high risk, and 12 as monitoring sectors. In 2016, the mapping was updated, with data from 13 of these areas. We emphasize that the area called Beira Rio was eradicated by the city hall. In cooperation with the Housing and Urban Development Company – CDHU and the municipality, through the Morar Bem Program, 391 new houses were designed and built only for families in risk areas. Removing houses in the Beira Rio area eliminated the risk, as risk analysis is a relationship between the expected process typology and its probability or potential of occurrence versus the vulnerability of the elements at risk and the potential for damage. With the removal of the element at risk, in the case of houses and their residents, even if floods continue to occur, there will be no damage to these elements. From the 13 mapped areas, it can be observed that the actions taken by the municipality helped to reduce the degree of risk.From these observations, 21 risk sectors were mapped and classified into 16 landslide risk and 5 flood risk sectors. The landslide risk sectors were classified as 04 high risk and 12 as monitoring sectors. Through the actions of the municipality, the 02 sectors of very high risk were eliminated or had the degree of risk reduced due to structural interventions.

1 INTRODUCTION

The Municipal Risk Reduction Plan (MRRP) is an instrument that subsides the municipal politics of urban and environmental development, housing provision and social inclusion, and also establishes actions of risk management that involve the three levels of the government. It contemplates:

(a) the identification of risks associated to landslides, bank undermining, and floods in the city's area (susceptible areas to the cited processes, that may affect housings located in reliefs that are not appropriate to occupation, like hills with a high declivity or valley bottoms and flood plains);

(b) analysis (mapping) or update of the areas with a risk of floods and landslides;

(c) sectorization and establishment of risk levels;

(d) estimatetion of affected housings;

(e) indication of structural and nonstructural interventions typologies needed to the reduction or elimination of the sectors with a risk or very high risk, also estimating the costs;

(f) indication of financial sources to implement these measures and;

(g) a course to capacitate the city's team.

IPT, since 2003, works on the elaboration of Mappings and Municipal Risk Reduction Plans (MRRP), have colaborated along with the Ministry of Cities the national method to execute the MRRP's.

This article aims to compare the Municipal Risk Reduction Plans made in 2012 to the one made in 2016 for the city of Arujá, SP, to check the efficiency of the plans as a tool of risk management.

2 METHOD

The adopted method to the work development constitutes in data acquiring and analysis, essentially the data existing in the Town Hall, City's Civil Defense, and other sources (newspapers, institutions files and others).

It is from the City Hall's responsibility to provide project copies, plans, areal photos and studies referent to the theme, including: the historic of interventions in the risk sectors, historic of occurrences in the risk sectors, altimetric plans, photographic documents, and other materials.

The data are systematized to establish criteria and procedures to evaluate the sectorization of risk areas, with the goal to subside the risk management, as to set technical and social parameters, along the city hall's technicians, aiming to promote major security to the people and/or eliminate the risks.

The most critical areas to landslides and floods correspond, most of the times, to non-consolidated occupation which the infrastructure, sometimes, is precarious, without equationating the processes on the relief towards the interventions made by the occupation.

In the mapped areas, it is analyzed potential situations to landslides, undermining in rivers, and floods, being adopted the following procedures:

a. Inspect each area over geological-geotechnical investigation on relief, aiming to identify the conditions to instabilization processes, instabilization evidences, signs of destructive processes development, and gravity of processes over elements to the risk of landslides;

b. Inspect each area over geological-geotechnical on relief, aiming to identify triggering elements of the process, evidences and signs of hitting, evidences of the range of the process, and the gravity of the process over the flood risk;

c. Registrate characteristics from each mapped sector and results of the geological-geotechnical investigations;

d. Delimitate the risk sectors, representing them in areal oblique photos from helicopters or drones and in orthophotos, in Geographical Information System (GIS) environment;

e. Estimate potential consequences of the expected process, over evaluations from possible acting destructive process outcomes (e.g., mobilized volumes, debris trajectory, reaching area, maximum level of flooding, etc.), and the number of threatened houses in each risk sector;

f. Evaluate and define risk level of the instabilization process (landslides, floods and BANK UNDERMININGS), valid for a period of 1 (one) year, according to criteria from the method for risk areas mapping (Ministry of Cities, Institute for Technological Researches, 2007); and

g. Indicate appropriate alternative interventions for sectors with a risk level of R3-HIGH and R4- VERY HIGH, with their respective cost estimate.

2.1 Selected Area

2.1.1 Location, Geology and Geomorphology

The chosen area was the city of Arujá, in the São Paulo State. Figure 1 shows the location of the city.

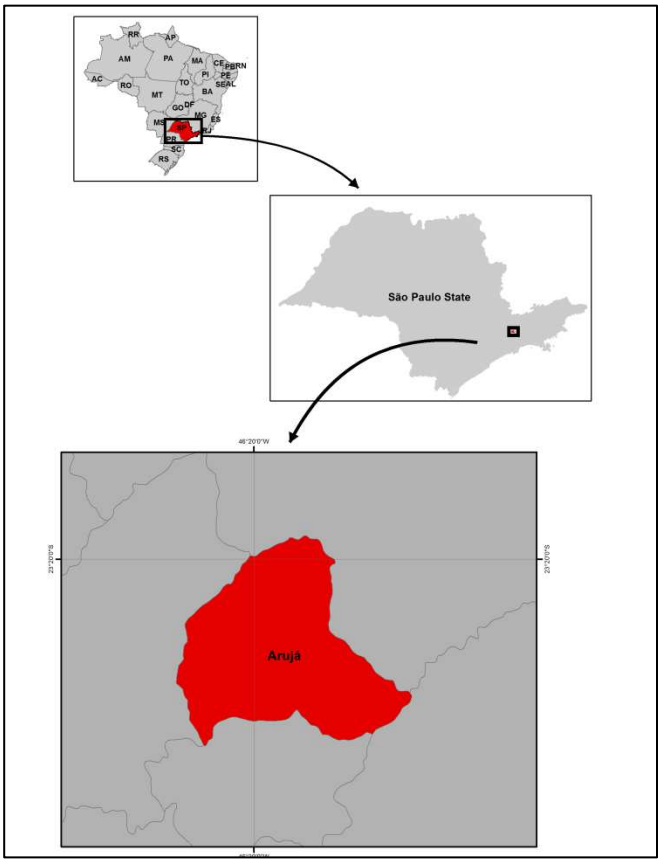

Figure 1 – Location of the area.

Geologically, there are both sedimentary and crystalline rocks in the city of Arujá, and the last is most commonly found in the territory (Perrota *et al.,* 2006). Metamorphic rocks from the Embu Complex and igneous rocks from the Granitic Complex Santa Isabel are the ones predominant in the city, with also the outcrop of sedimentary rocks from the Resende Formation, metamorphic from São Roque group, and also the Serra do Itaberaba group, besides recent alluvial deposits on the margin, bottom valleys and river floodplains.

The Aruja's relief is all compounded by reliefs of degradation in dissected plateaus (IPT, 1981). In the south-west, small hills with low spikes are found, where low declivities predominate, up to? 15% and local amplitudes minor than 100 meters. In the central area of the city, low hills are found, predominating medium to high declivities, over 15%, and local amplitudes also minor than 100 meters. In the North and East of the city, parallel hills are found, where declivities from medium to high predominate, over 15%, and local amplitudes from 100 to 300 meters.

2.1.2 Developed Works

The 14 risk areas were mapped in Arujá in 2016, the same that were mapped by IPT in 2012's MRRP.

Both MRRPs were designed by the city's request. The first was made in 2012 and, after the decision making to mitigate and eliminate risks, the city requested the second PMRR in 2016, aiming to reclassify the levels of risk.

In all selected areas, it was used photos obtained in 2012 through a helicopter overflight, with medium highs of between 100m and 150m from the relief. In those images, the sectors delimitation that were identified in fieldwork were drawn, updating the ones from the mapping in 2012. Ortophotos were also used with the goal of spatializing the area's distribution.

The data obtained were organized and systematized over maps, forms and photographical documentation, being integrated to facilitate the analysis and diagnostics to risks evaluation.

3 RESULTS AND DISCUSSION

In 2012's mapping, 19 landslide risk sectors and 07 flood risk sectors were identified, totalizing 33 sectors and 1.619 housings (IPT, 2012). Table 1 shows the risk level in each mapped sector as long as the identification of the process.

In 2016, 16 landslide risk sectors and 06 floods risk sectors were mapped, totalizing 21 sectors and 1461 housings (IPT, 2016). Table 2 presents the risk level in each mapped sector as long as the identification of the process.

In addition to a decrease in the number of mapped sectors in 2016, there was a reduction and/or elimination of major risks mapped when compared to 2012, as showed in Figures 2 and 3for landslides and floods, respectively. Figure 4 presents an example of a mapped area in both 2012 and 2016 where the risk level has decreased.

Table 1–Results from the mapping made in 2012.

Area name	Name Code	Process	Risk Level

Jardim Josely	AR-01-01	Flood	R3 – High
	AR-01-02	Flood	R4 – Very High
Estância Pacaembu	AR-02-01	Flood	R2 – Medium
	AR-02-02	Landslide	R2 – Medium
	AR-02-03	Landslide	R4 – Very High
Cachoeirinha	AR-03-01	Landslide	R2 – Medium
	AR-03-02	Landslide	R1 – Low
Jovens da Verdade	AR-04-01	Landslide	R2 – Medium
	AR-04-02	Landslide	R3 – High
Serra Pelada I	AR-05-01	Landslide	R2 – Medium
Serra Pelada II	AR-06-01	Landslide	R2 – Medium
Mirante II	AR-07-01	Landslide	R2 – Medium
	AR-07-02	Landslide	R3 – High
	AR-07-03	Landslide	R4 – Very High
Pinheirinho	AR-08-01	Landslide	R2 – Medium
Vila Pilar	AR-09-01	Landslide	R3 – High
	AR-09-02	Landslide	R2 – Medium
Penhinha	AR-10-01	Flood	R2 – Medium
	AR-10-02	Flood	R3 – High
Jardim Santo Antonio	AR-11-01	Landslide	R2 – Medium
	AR-11-02	Landslide	R3 –High
	AR-11-03	Landslide	R2 – Medium
Retiro	AR-12-01	Landslide	R2 – Medium
	AR-12-02	Landslide	R3 –High
Nippon	AR-13-01	Flood	R2 – Medium
Beira Rio	AR-14	Flood	R4 – Very High

This reduction in the degree of risk is due to the implementation of public policies that brought structural interventions, such as the constructions aiming the reduction and/or elimination of the risk, the reallocation of residents and the removal and destruction of the former housings. Table 3 presents the number of people living in risk areas in 2012 and in 2016. This number includes both flood and landslide risk areas.

Table 2 – Results from the mapping uptade in 2016

Area name	**Name Code**	**PROCESS**	**Risk Level**
Jardim Josely	AR-01-01	Flood	R2 – Medium
Estância Pacaembu	AR-02-01	Flood	R2 – Medium
	AR-02-02	Landslide	R2 – Medium
Cachoeirinha	AR-03-01	Landslide	R2 – Medium
	AR-03-02	Landslide	R1 – Low
Jovens da Verdade	AR-04-01	Landslide	R2 – Medium
	AR-04-02	Landslide	R3 – High
Serra Pelada I	AR-05-01	Landslide	R2 – Medium
Serra Pelada II	AR-06-01	Landslide	R2 – Medium
Mirante II	AR-07-01	Landslide	R2 – Medium
Pinheirinho	AR-08-01	Landslide	R2 – Medium
Vila Pilar	AR-09-01	Landslide	R3 – High
	AR-09-02	Landslide	R2 – Medium
Penhinha	AR-10-01	Flood	R2 – Medium
	AR-10-02	Flood	R3 – High
Jardim Santo Antonio	AR-11-01	Landslide	R2 – Medium
	AR-11-02	Landslide	R3 – High
	AR-11-03	Landslide	R2 – Medium
Retiro	AR-12-01	Landslide	R2 – Medium
	AR-12-02	Landslide	R3 – High
Nippon	AR-13-01	Flood	R2 – Medium
Beira Rio	AR-14	Extinct Area	Extinct Area

Table 3 – Comparison between the number of housings in risk areas in 2012 and 2016.

	R4	**R3**	**R2**	**R1**
2012	110	47	1441	21
2016	0	26	1412	21

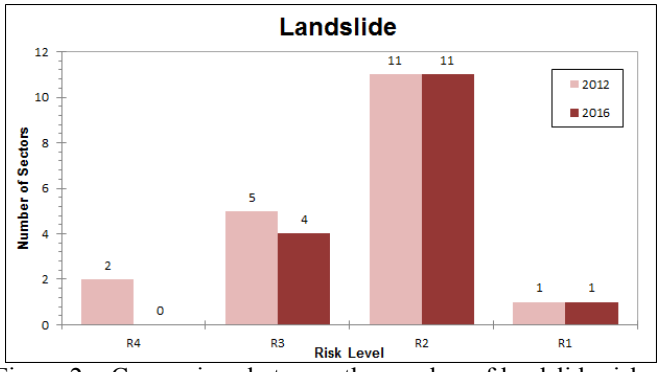

Figure 2 – Comparison between the number of landslide risk sectors by risk level mapped in 2012 and 2016.

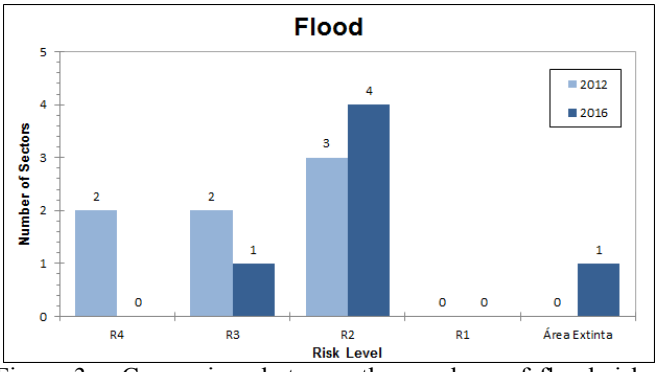

Figure 3 – Comparison between the numbers of flood risk sectors by risk level mapped in 2012 and 2016.

Figure 4 – (a) Area AR-01 mapped in 2012 presenting 2 risk sectors (R3) and (R4); (b) Area AR-01 mapped in 2016 presenting only one risk sector (R2).

From now on, a comparative analysis area to area between the situation observed in 2012's MRRP and the situation that was observed in the MRRP realized in the months of November and December of 2016 will be presented,.

In the Rosely neighborhood (AR-01), interventions were made, such as:

- cleaning services in the Taboaozinho stream channel;
- Segment install under Esperança street (1,5 meters tall and 1,0 meter wide), besides 2 tubes of 0,8 meters already existent in the 2012's mapping.
- Channel's enlargement; and
- Channel's deepening.

These structural measures reduced the flooded area at the place and reduced the gravity of the process on the elements at risk.

In the Estancia Pacaembu area (AR-02) the risk level reduction is associated to:

- Construction of a contention wall on the basis of the First Street, which contained a landfill that presented movement signs, like cracks on the relief, curved walls, inclined trees and lampposts and landslide scars;
- Conclusion of a house building in the sector, with a contention wall in the backyard, on First Street;
- Street paving; and improvement on the sector's drainage.

The Cachoeirinha area (AR-03) continued with almost the same characteristics and risk level. Changes observed between 2012 and 2016 that helped to control and reduce the risk were the increased number of houses in the area, from 61 to 63, improvement in the general superficial drainage system and also those within the houses.

The Jovens de Verdade area (AR-04), according to comparative analysis between the two mappings, remains with the Sector AR-04-01 and with the same characteristics and Medium risk level Medium (R2). The differences observed between 2012 and 2016 maps were the number of houses, from 184 to 203, besides improvements in the conditions of the previously existent houses . However, the Sector AR-04-02 remains with almost the same characteristics and High risk level (R3), and apparently there were no structural measures to reduce the risk level from High (R3) to Medium (R2).

In Serra Pelada I area (AR-05), the circumscribed sector remains, almost with the same characteristics and Medium risk level (R2). The differences observed between the maps that helped in the control and risk reduction were the increased number of of houses in the area, from 513 to 521, and the improvement of the general superficial drainage system and also those within the houses.

In the Serra Pelada II area (AR-06), according to comparative analysis, the Sector AR-06-01 remains almost with the same characteristics and Medium risk level (R2). The differences observed between one mapping and the other that may help on the control and risk reduction were the increased number of houses numbers in the area, from 185 to 192, and the improvement of the general superficial drainage system and those within the houses.

On the comparative analysis from Very High and High risk level sectors mapped in 2012 at the Mirante II area (AR-07), there has been a reduction from these risk levels to Medium (R2). This reduction occurred because of:

- Terrain waterproofing and superficial drainage system executed on the top of a slope located on the backyard of the 5 houses that were part of the sector AR-07-02, located on the Macuco street;
- Re-sloping the natural basis slope, close to Juriti Street, former Sector AR-07-03;
- Construction of contention wall on the basis of the natural slope, close to Juriti Street, former Sector AR-07-03;
- Correct water catchment and conduction from a water mine located on the basis of a natural slope, former Sector AR-07-03;
- Conclusion of the construction of two houses , on the former Sector AR-07-03, with contention walls on the backyards of both, located on the Juriti Street;
- Demolition of a house at an imminent risk of collapse, on the former Sector AR-07-03, following the instructions given by IPT in 2012; and
- General improvement on the sector's drainage system.

The Jardim Pinheiro neighborhood (AR-08), sector AR-08-01 continues almost with the same characteristics and Medium risk level (R2). The only change observed between 2012 and 2016 that could have helped to control and reduce the risk was the improvement in the superficial drainage system.

In the Vila Pilar area (AR-09), through a comparative analysis between the mappings, it was possible to notice a reduction on the number of houses in the risky area of the Sector AR-09-01, from 05 to 03, due to: construction of contention walls in the backyard of the and execution of a drainage system on the top of the slopes from two houses. In Sector AR-09-02, according to the comparative analysis between the mapping made in 2012 and the one from 2016, there was a reduction from 52 to just 01 house in the risk sector due to: execution of drainage system on the top of the natural slopes and improvement on the housing densification.

The comparative analysis between the two mappings for Jardim Penhinha (AR-10) showed a reduction in the number of houses on both years. This reduction in risk is related to: canalization, channel deepening and enlargement downstream of the area; cleaning on the non-rectified stretch between the area and the construction made.

In the Jardim Santo Antônio area (AR-11), the Sector AR-11-01 continues with almost the same characteristics and Medium risk level (R2). Improvements were observed on the surroundings of the older houses, specially the construction of contention walls and upgrades in the superficial drainage system, which justifies the reduction in the number of houses in the area, from 44 to 08. However, the Sector R-11-02 continues with the same general characteristics and High risk level (R3) as there were not any apparent changes between 2012 and 2016. On the other hand, the Sector AR-11-03 was extinct because of the improvements made in the area of the two houses in the sector, such as contention walls and upgrades in the drainage superficial system, justifying the unusual condition.

In the Retiro area (AR-12), according to comparative analysis between, the Sector AR-12-01 continues with almost the same characteristics and Medium risk level (R2). The observed differences between the mappings were the increase in the number of houses, from 89 to 103, and the improvement on their conditions. From the 14 houses added to the sector, 09 came from the former Sector AR-12-02 ,because of the improvements made there.

In the Sector AR-12-02 from the Retiro area there was a reduction from 09 to 01 house due to the construction of contention walls on backyards

of the houses; streets paving; superficial drainage system execution; and sector density.

In the comparative analysis for Jardim Nippon area (AR-13), the Sector AR-13-01 continues with almost the same characteristics and Mediumrisk level (R2). The changes observed between 2012 and 2016 that helped to control and reduce the risk were the improvements on the conditions of the houses and the area drainage system, in addition to a increased area of some houses. These measures reduced the area from the flood range.

In the mapping made in 2012, the area Beira Rio (AR-14) was pointed as a problem to the municipality In mapping made in 2016, it was observed that the area is being eradicated by the City. In a joint-work from the city with the Habitational and Urban Development Company - HUDC, over the program "Morar Bem', 391 houses were built and destined to families that were originally in risk areasy, including the Beira Rio Area.

4 CONCLUSION

The mapping made in 2016 was updated, considing the same areas mapped in 2012, totalizing 13 risk areas.

Of the 13 mapped areas, two of them reduced the risk level from Very High (R4) and High (R3) areas because of structural interventions.

Besides these two reductions, this papers highlights that the Beira Rio area (AR-14) was completely eradicated through a cooperation of the Habitational and Urban Development Company - HUDC and city throughr the program "Morar Bem", 391 new houses were built and addressed exclusively to families that previously lived in risk areas. Removing houses from the Beira Rio region eliminated the risk, since the risk analysis is a relation between the expected process typology and its probability or potential of occurrence versus the vulnerability from the elements at risk and the damage potential. With the removal of the risk element, in this case the houses and their habitants, while the flood continues, there will be no damages to the elements.

It is possible to conclude that the effective action plan from the city with structural measures implemented in the risk areas allows the reduction of the risk level. It is important to address that the pointed interventions aim to reduce the risk level and not to urbanize the referred areas.

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