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THE OCCURRENCE OF FLOODS IN SÃO PAULO, BRAZIL: THE IPIRANGA STREAM BASIN CASE STUDY

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Abstract

The present study refers to the occurrence of cyclical and constant flooding in the Metropolitan Region of São Paulo (RMSP). The RMSP presents every year in the summer, riverside roads and avenues with interrupted or hindered traffic. Properties near the rivers are also affected by the elevation and overflow of the water level on the flood plains. The objective of this work is to apply the multitemporal perspective in Integrated Landscape Analysis method, to fully evaluate the physical and anthropic environment factors, as well as how the changes that occurred over time were responsible for the landscape configuration and reconfigurations. The case study is the Ipiranga Stream Watershed, in the city of São Paulo/SP, which recorded 82 flood events between 1965 and 2017, predominantly in the period between 2010 and 2017 (46 events). The events occur due to the combination of natural characteristics - the elongated shape and low watershed slope, the rise of 24h amount and intensity rainfall, and anthropic characteristics, such as the expansion in soil impermeability rates and structural changes in the main channel and tributaries. The data survey shows the ineffectiveness of structural measures, highlighting that some additional measures need to be implemented to minimize damages.

Keywords: metropolitan floods, urban watersheds, urban flood management,

1. INTRODUCTION

The changes imposed by men in the urban environment trigger or accelerate the geomorphological processes, often de-characterizing the original physical environment. These changes cause environmental damage and consequences, such as the induction of landslides, floods, subsidences, among others. Ultimately, these consequences cause social and economic risks and losses to man himself (Leopold, Wolman ve Miller, 1964, Ward, 1978; Goudie, 1994; Guerra ve Marçal, 2006; Szabó, Dávid ve Lóczy, 2010; Moroz-Caccia Gouveia, 2010).

According to data from the Swiss RE Institute (2018), the total economic losses due to natural disasters in 2017 were in the order of USD 337 billion. Regarding global social data, more than

11,000 people lost their lives or disappeared when these disasters occurred, while millions were left homeless.

Currently, floods are the type of natural disaster that occurs most frequently in the world, with impacts related to human (dead and affected) and financial losses. The occurrence of floods in urban areas has been intensified by the waterproofing of soils, by the occupation of the plains and also by the anthropic changes in watercourses, such as rectifications and plumbing.

In bibliographic reviews there are several concepts for flooding. For this work, it was decided to adopt the overbank flood or simply flood that represents the overflow of the waters of a watercourse, reaching the floodplain or lowland area (Carvalho, Macedo ve Ogura, 2007; Amaral ve Ribeiro, 2009). Flood occurrences, which are defined by the elevation of the water level in the drainage channel, due to the increase in flow, reaching the maximum level of the channel, without overflowing however, are not included in this analysis. Urban flooding, which represents a momentary accumulation of water in certain places due to deficiency in the drainage system and is not related to the dynamics of water courses, will not be considered in the analysis either.

Floods in urban basins have been discussed in several recent studies, which address issues related to land use, occupation and anthropogenic changes, which supplanted the natural morphological characteristics of the original landscape, without observing that the river plains played the role of river floods dampening. Among these studies, Faccini et. al. (2015) and Faccini et. al. (2016) in Italy, Boudou, Danière ve Lang (2016) in France, Cœur ve Lang (2008) who evaluated historical data from Europe, and Rodrigues (1997, 2005), Moroz-Caccia Gouveia (2010) and Luz (2010) with applied studies in the Metropolitan Region of São Paulo / SP.

In São Paulo, the process of occupation of floodplain areas began in the 1930s, with the rectification of its main river, the Tietê River, for the future implementation of marginal avenues and the use of central areas. Those actions were motivated by sanitation and salubrity, which, based on the hygienist principle, aimed to capture and conduct surface runoff quickly through channeling and rectification of natural channels. Soon after, the rectification of another important river, the Pinheiros River, took place to conduct the water to the Henry Borden Power Plant in order to generate electricity. As a consequence, the rectifications freed up the floodplain areas and grounded meanders for real estate projects. Later, with the Avenues Plan, in the 1950s, this model was adopted in other areas. In the 1970s, floodplains and valley bottoms were institutionalized as axes for the expansion of urbanization by the government at the time. Thus, the occupation of the floodplain areas of water courses was not only the result of disorderly occupation, but also of an action of political incentives for real estate projects and for the installation of important road systems (Seabra, 1987; Rolnik, 1999; Custódio, 2002; Travassos, 2004; DAEE, 2012; Kanashiro, 2013; Anelli, 2015).

This article presents the case study of the urbanized basin of Ipiranga Stream in São Paulo / SP, which since the 1930s has had recurrent floods, which affect the local population since the occupation of the floodplain areas in the 1960s. With the application of the Integrated Landscape Analysis under a multitemporal perspective, it was sought to determine the behavior of the factors of natural and anthropic environment that contributed to the imbalance of the dynamic relationship between society and nature and that influenced the increase in the occurrence of floods in the area in the last decades.

The Integrated Landscape Analysis is based on the conceptions of Geosystems, developed by Bertrand (1971), Sotchava (1978) and Monteiro (2000), in the studies of Ecosystem and

Ecodynamics, by Tricart (1977), and Environmental Fragility, developed by Ross (1994). To analyze the dynamics of the system, as recommended by Cooke ve Doornkamp (1990), the data were evaluated from a long-term perspective. Therefore, in addition to the integration of information from the physical and anthropic environments, it is important to add the multitemporal analysis, which starts from an initial state, that is, from the earliest information on a given area, and, over the period evaluated, seeks to identify which alterations occurred in the factors of the physical and anthropic media caused changes in the dynamics of the landscape. In urban areas, physical factors must be correlated with the evolution of land use. Based on studies of past events, one can observe the evolution of the frequency and magnitude of the phenomena to propose effective damage mitigation measures.

For the analysis, the variables that contemplated the natural aspects of the basin were selected, such as morphology and rainfall and anthropic interventions, such as soil waterproofing and changes in drainage channels. The results show that the floods are conditioned by the natural characteristics of the basin, as its shape and low slope favor the accumulation of water and slow runoff, in addition to the increase of annual rainfall totals. As anthropic characteristics, we highlight the expansion of soil impermeability and the interventions carried out on the main channel and tributaries of the stream, which intensified the incidence of flood events in the basin.

2. MATERIALS AND METHODS

The proposed methodology seeks to analyze the landscape components from a multitemporal perspective. Data on natural components (landforms, drainage and precipitation characteristics) and anthropic components (history of floods recorded in the basin, soil impermeability and land use rates, changes in water courses) were used for analysis, from a comparative perspective over a few decades.

The landforms and the characteristics of the drainage network were analyzed based on the elaboration of slope, hypsometric and geomorphological maps, in a scale 1: 50.000, for the assessment of the natural susceptibility of the basin to floods. The cartographic base, hydrographic data, the delimitation of the basin and the level curves with equidistance of 5 meters were obtained from the official base of the Municipality of São Paulo (PMSP-Digital Map of the City of São Paulo, 2017) and from planialtimetric sheets of the Metropolitan Cartographic System, prepared by EMPLASA (1980/1981). To analyze the morphology of the basin, the classification proposed by Strahler (1957) and the parameters defined by Horton (1945) were initially applied for quantitative analysis of watersheds and drainage channels. The morphometric parameters of the drainage basins are strongly correlated to their hydrological characteristics and, therefore, were evaluated to estimate their influence on floods, as proposed by Zăvoianu (1985) and Kochel (1988). In addition to the morphological parameters, the characteristics of the valleys and the transversal profiles were associated as instruments of analysis, based on the elaboration of a geomorphological and hypsometric map (Ross, 1992).

Precipitation information was obtained from IAG-USP Meteorological Station E3-035, located upstream of the basin, for the period between 1933 and 2016, and Climatological Bulletin (IAG-USP, 2016), in order to verify possible changes in the climatic behavior that could cause greater volumes of rain in the basin. Studies previously carried out in the study area and at a regional level were surveyed to parameterize the analysis.

To assess the history of flooding in the basin, information from Santos ve Amaral (2017) was collected, who consulted the following media and official source/period: data from the digital newspaper Ipiranga News were accessed for the period between 2009 and 2016; the digital collection of the Folha de São Paulo newspaper allowed access to editions from the period between 1960 and 2016; the digital collection of the Estado de São Paulo newspaper allowed access to editions from 1875 to 2017; the Emergency Management Center (CGE / PMSP) file covered the period from 2000 to 2017. In addition to the survey carried out by Santos ve Amaral (2017), data from the São Paulo State Flood Alert System file were evaluated, Department of Water and Electricity, Hydraulic Technology Center Foundation (SAISP/DAEE/FCTH), which comprised the period from 2007 to 2017. There were analyzed as proposed by IG (2009), Gutjahr *et al.* (2010) and Fernandes da Silva *et al.* (2014), with registration in pre-established forms, in order to allow comparative assessment and standardized data. The flood history aims to verify the points in the basin where the floods occurred, and whether, over time, there was an increase in the number of sites affected and the recurrences in each of these sites.

In order to assess the changes generated by the anthropic impact of population growth and the consequent waterproofing of the surface, it was decided to resort to a multitemporal analysis, based on maps, aerial photographs and satellite images, in order to limit the progress of the built areas and the anthropic and structural changes in the main channel and tributaries over the last century, as proposed in Boudou, Danière ve Lang (2016), Faccini *et al.* (2015), Faccini *et al.* (2016) and Cœur ve Lang (2008). Maps from the SARA BRASIL Project (1930) were consulted, the aerophotogrammetric images from the years 1940 and 1954, obtained from PMSP (Digital Map of the City of São Paulo, 2017), and from 1958 and 1994, which, as well as the images of the years 2010 and 2017, were obtained from the collection of the Geological Institute (IG) (digital material).

3.RESULTS AND DISCUSSIONS

The proposed methodology was applied to the Ipiranga Stream Basin, located between the neighborhoods of Água Funda and Ipiranga, south of the city of São Paulo/SP, which annually presents flood events that restrict the circulation in roads and cause damage in homes and businesses. The stream is one of the main tributaries of the Tamanduateí River, part of the Alto Tietê Water Resources Management Unit, which covers the municipalities of São Paulo Metropolitan Region (Figure 1).

According to DAEE (2011), the floodplain area of the Alto Tietê Basin, according to projections, may have been reduced from 140 km² to 70 km², reducing the water retention time from 48 to 12 hours due to its occupation and consequent waterproofing.

The Alto Tietê Macrodrainage Master Plan (FABHAT, 2016) assessed the situation of the existing structures in the RMSP for dampening rainwater. There are currently 36 reservoirs that total a reserve volume of more than 5 million m³. The construction of another 104 new reservoirs in the basins composing the Alto Tietê is also planned. The total volume to be stored in the new 55 holding reservoirs planned for the entire Tamanduateí River basin is around 9 million m³, of which 9 of these are designed for the Lower Tamanduateí River Basin, of which the Ipiranga Stream is an affluent (DAEE, 2012). This data points out that the problem of urban flooding occurs at a regional level and not just at a local one. According to FABHAT (2016), the contribution of the Tamanduateí River represents about 40% of the maximum flow in the main channel (Tietê River). This same study indicates that only structural measures in the basin are not sufficient to contain new floods, highlighting the importance of non-structural measures, such as the preservation of permeable green areas.

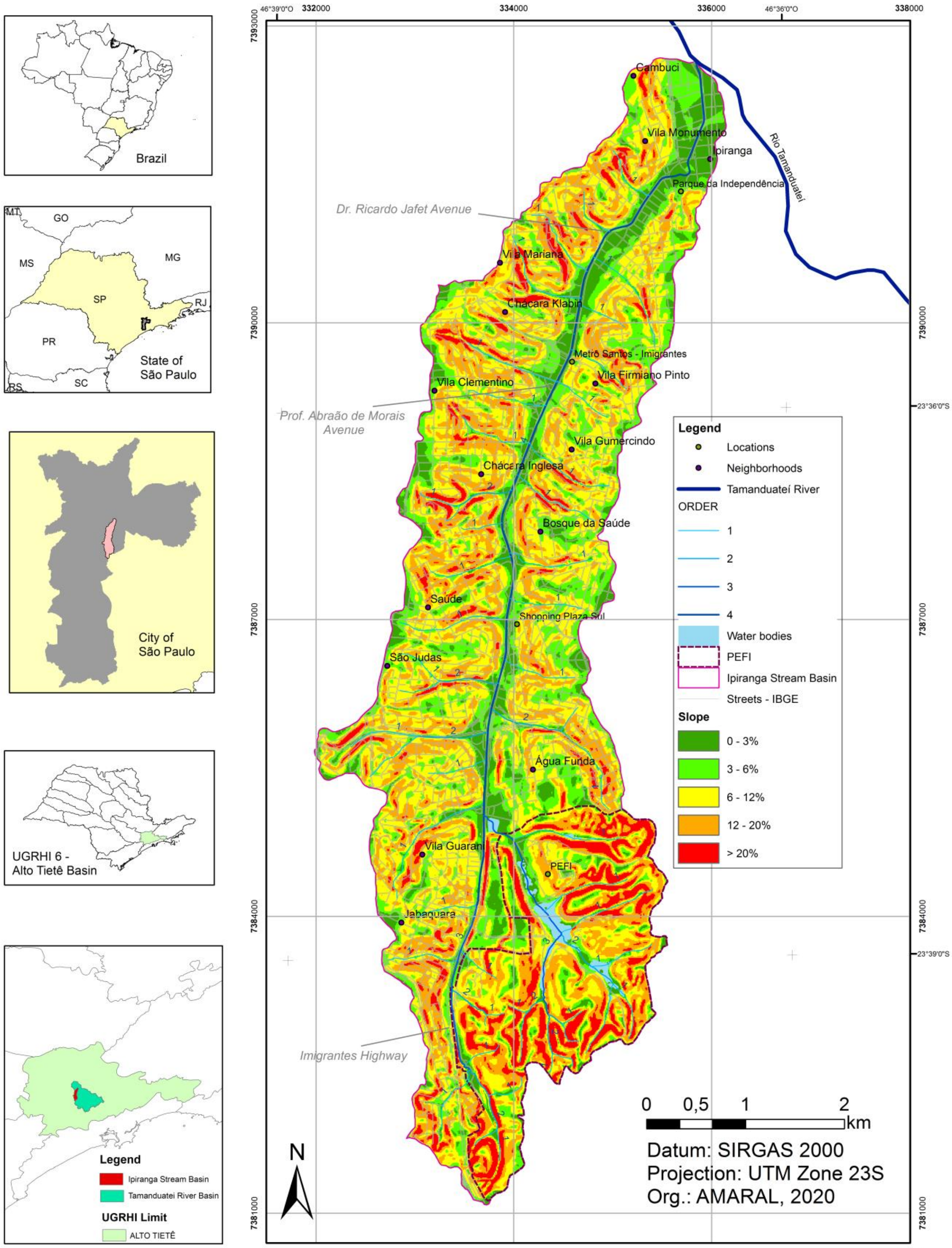


Figure 1: Location of the Ipiranga Stream Basin, São Paulo/SP, with slope classes and hierarchical order of the channels (according to Strahler, 1957).

Rodrigues (2015) analyzed studies that compared the storage capacity of the temporary retention reservoirs built in the RMSP in relation to the amount of rainwater that would be stored in the river plains of the same region. In case it was not occupied and waterproofed, the original compartment of the floodplain would store 353 million m³ of water, which is equivalent to the construction of 1,772 reservoirs, with an average volume of about 200 m³ each.

Along the banks of the Stream are the avenues Dr. Ricardo Jafet and Prof. Abraão de Morais, roads that connect the south zone to the city center, presents a large flow of vehicles, and considerable commercial and residential infrastructure. These avenues are also important accesses from the capital to the coast via Imigrantes Highway (Figures 2 and 3).

The length of the main course is approximately 11 km and its contribution area corresponds to 23 km². Approximately 80% of the basin's area is urbanized and the remaining 20% is represented by the residual forest of the Fontes do Ipiranga State Park (PEFI), where the main sources of the stream are located. PEFI is one of the most significant remnants of the Atlantic rainforest inserted in an urban area in Brazil, with an area of 4.8 km².

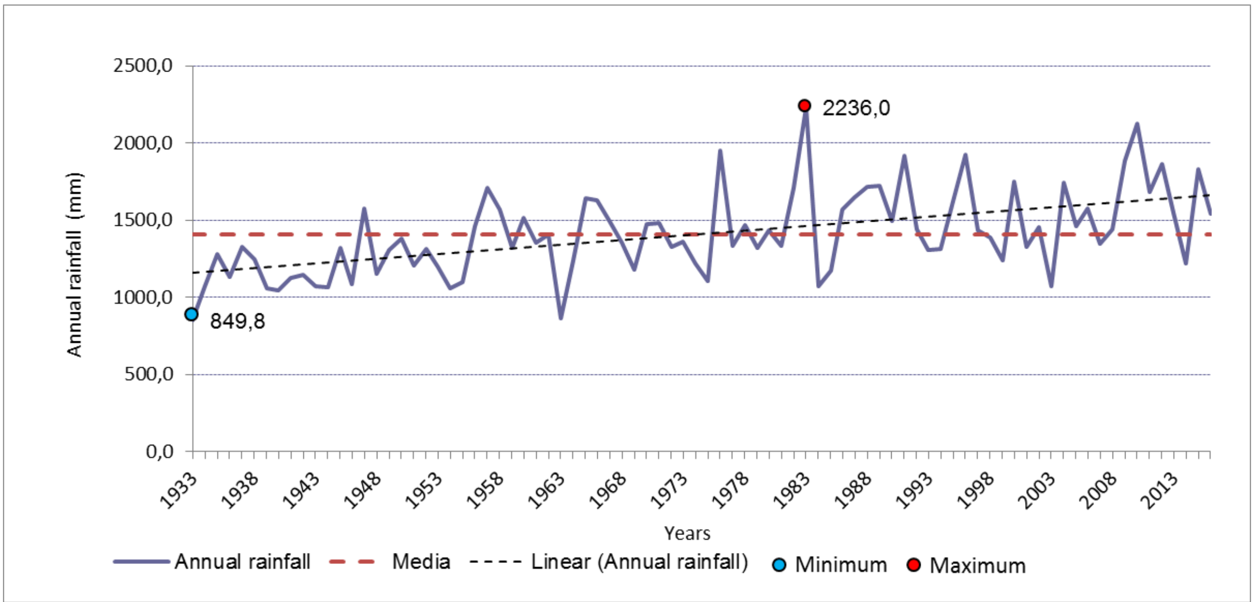
As main physical and drainage characteristics, the basin has a dendritic pattern, elongated and rectangular shape, S-N orientation, with a predominance of low to medium declivity, between 0 and 12%. The main course of the drainage network is 4th order, and the tributaries are perpendicular to the main course and most are 1st order channels. The main channel gradient is 0.57%. These values of slope of the basin and channel, as well as the elongated shape of the basin, are generally associated with a low to moderate level of susceptibility to flooding. The hypsometry of the basin has altitudes that vary between 730 and 836 meters. The topographic range between the largest divider and the mouth of the basin is 106 meters. Transverse profiles show that from the medium course downstream the river plain becomes wide and flat, favoring slow flow and accumulation of rainwater.

Figure 2 - View of the middle course of the basin towards the upstream. On the banks of the Ipiranga Stream are the lanes of Prof. Abraão de Morais Avenue. Photograph: Amaral, 2018.

Figure 3 - View of the medium course towards the downstream. On the banks of the Ipiranga Stream are the lanes of Dr. Ricardo Jafet Avenue. Photograph: Amaral, 2018.

Regarding rainfall characteristics, the analysis reveals that in the period between 1933 and 2016 there is a tendency of increase by about 30% in the annual rainfall index, which corresponds to an increase of about 500 mm in the annual totals of the last years, and an increase of 2.3 ° C in relation to the average temperature (IAG, 2016). The average annual rainfall in the period was 1,409.5 mm, the maximum annual value occurred in 1983, with 2,236 mm and the minimum value in 1933, with 849.8 mm (Figure 4). The monthly maximum rainfall occurs in the months of January and March, which characterize the intense and concentrated rains in the summer period, when there is a greater frequency of floods. In the average of the evaluated period, the maximum in the month of January reached 653.2 mm and in the month of March 470.7 mm.

Monteiro (1973) indicated that the high and the low amounts of annual rainfall are justified by the Tropical and Subtropical Climates that can present alternately dry and moist years. São Paulo and the Metropolitan Region of São Paulo are crossed by the Tropic of Capricorn what influences, as a transition band, in the annual distribution of rainfall, sometimes more to the south, other times more to the north. The proximity of the Atlantic Ocean (56 km), the altitude of 856 m and the dynamics of the urban climate can also influence in the disponibility of water vapour and the formation of rainfall.



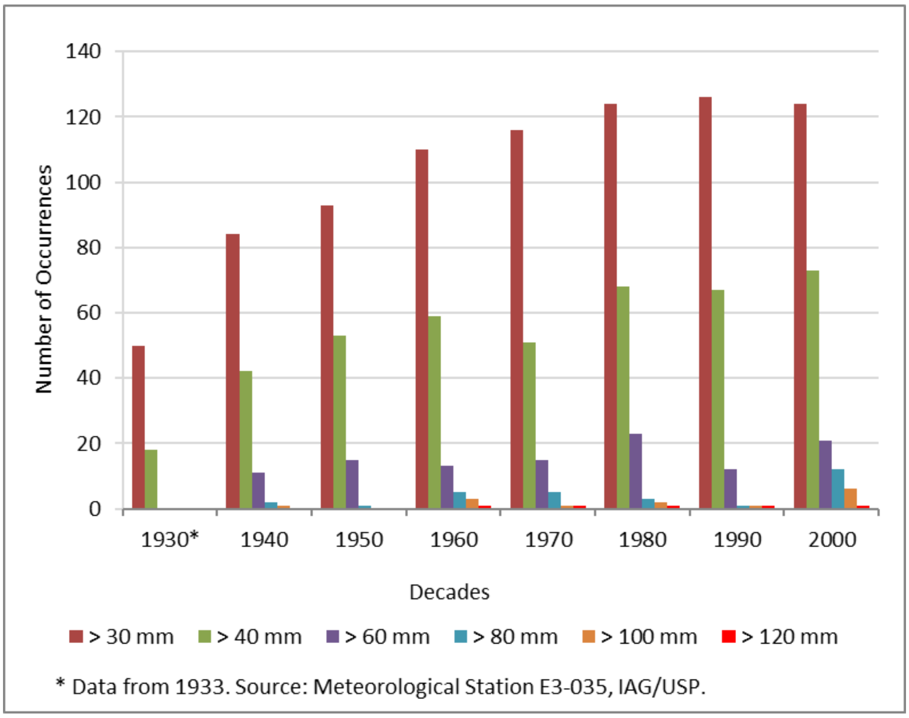
Data source: Meteorological Station E3-035 from IAG / USP (2016). Org.: Amaral, 2018.

Figure 4: Annual rainfall data in the Ipiranga Stream Basin, São Paulo / SP, with a linear trend (dotted line), between 1933 and 2016.

Ferreira ve Amaral (2017) found that from the 1940s on, rainfall became more intense in the place, with the occurrence of several and frequent events above 60 mm in 24 hours. Since the 1960s, more episodes of extreme rainfall greater than 80 mm/day have occurred, and in that same period, there has been the occurrence of at least one rainfall greater than 120 mm/day in each decade (Figure 5). In March 1966, a 24-hour rainfall was recorded, which stood out as the record for the period, with 145.9 mm (IAG, 2016).

Xavier, Xavier ve Dias (1994), also evaluated the data from Meteorological Station E3-035, but referring to the period between 1933 and 1986. The authors consider that changes in daily precipitation may occur due to the local effect, induced by urbanization, or due to a global scale climatic cause, or the overlapping of both. They point out that the first years of data collection at the station reflected the situation in a peripheral area, which was gradually modified by the anthropic occupation around the park. Therefore, rainfall data are more likely to show, throughout its temporal evolution, changes attributable to the influence of the urban environment. In the event that the highest rainfall increased in the summer, they attribute that they are due to the permanence of the ZCAS (South Atlantic Convergence Zone) in that period of the year. Another explanation of a climatic nature for the positive rainfall anomaly in São Paulo in the months of May and June would be the presence of El Niño more frequently in recent decades.

Tavares ve Silva (2008) also emphasize that the topographic configurations of the edges of the Atlantic Plateau, combined with the effect of the heat island in the metropolitan areas (Xavier, Xavier ve Dias, 1994), lead to abundant and concentrated rainfall in the summer period.



Source: Ferreira ve Amaral (2017). Org.: Amaral, 2018.

Figure 5: Daily rainfall totals greater than 30mm in the 1930s to 2000s, in intervals of 30, 40, 50, 60, 80, 100 and 120mm.

Zilli *et al.* (2017) evaluated the rainy events in the Southeast Region of Brazil and also found an increase in the number of days with precipitation and in the intensity and frequency of extreme rain events. The records identified that the variation in patterns occurs, particularly, close to the main urban centers.

Salvadore, Bronders ve Batelaan (2015) cite that studies in different countries have found increased rainfall in urban areas, comparing pre- and post-urbanization conditions, and concluded that the increase in rainfall was around 5 to 15%. However, there are still uncertainties as to which factors of local scale would have most directly interfered in this change. Among the main factors are changes in land use, changes in surface roughness patterns due to urbanization and air pollution.

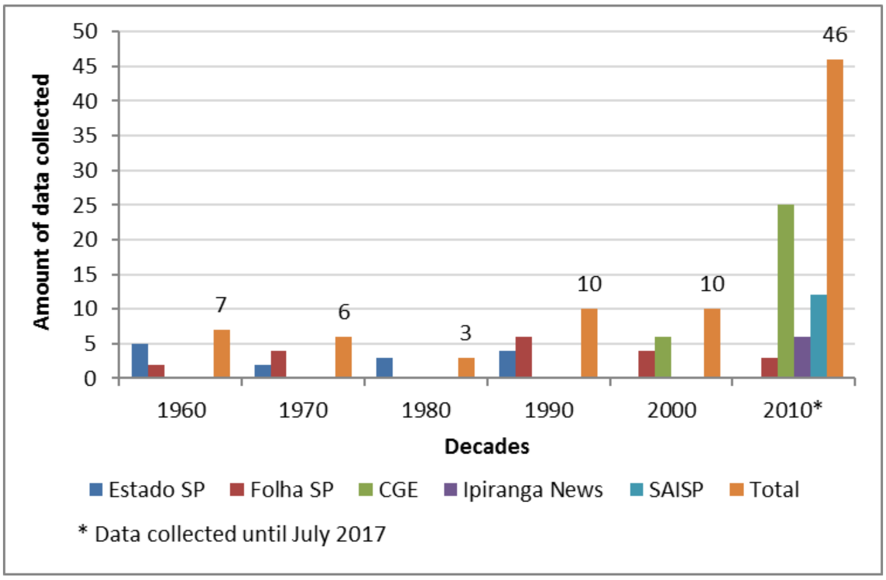
According to the studies presented, urbanization and the formation of heat islands can cause changes in the intensity of rainy events, especially in the summer, contributing to the occurrence of flooding events. However, a specific complementary study to prove this effect in the Ipiranga Stream Basin is necessary.

In relation to anthropic characteristics, we sought to correlate the history of floods recorded in the basin with soil impermeability rates, related to urban density, and the changes made in watercourses, over decades.

Data collected from consultations with digital information media (newspapers) and official sources (CGE/PMSP and SAISP/DAEE/FCTH) show that the amount of news reporting floods in the Ipiranga Stream Basin has increased in recent decades (Santos ve Amaral, 2017). No information was found prior to the 1960s, as before that period a large part of the area of the Stream plain was not occupied by dwellings and, therefore, floods were not recorded because they did not compromise human actions.

In total, 82 flood events were recorded in the basin in the period between 1965 and 2017, concentrated mainly in the last 3 decades, distributed as follows: 7 events in the period between 1965 to 1969, 6 in the period between 1970 to 1979, 3 between 1980 to 1989, 10 between 1990 and 1999, 10 between 2000 and 2009 and 46 events in the period between 2010 and 2017 (Figure 6).

In order to assess the changes generated by the anthropic impact of population density and the consequent waterproofing of the surface, it was decided to resort to a multitemporal analysis, based on maps, aerial photographs and satellite images, in order to delimit the progress of the built areas and the changes on banks and water courses.



Org.: Amaral, 2018.

Figure 6: Amount of data collected on flood events in the Ipiranga Stream Basin, São Paulo / SP, for decades and source of information.

Figures 7 to 10 show the multitemporal evolution of urban density, the structural works carried out and the recorded points of flooding. This evolution is portrayed in 4 time frames (1930 - 1962 - 1994 - 2017), with intervals of 32 years between the first scenarios (1930, 1962 and 1994) and 23 years until the last (2017). These intervals were defined according to the dates of the HPA January 15 2021 aerophotogrammetric and satellite images obtained, which were used in the interpretation of urban density.

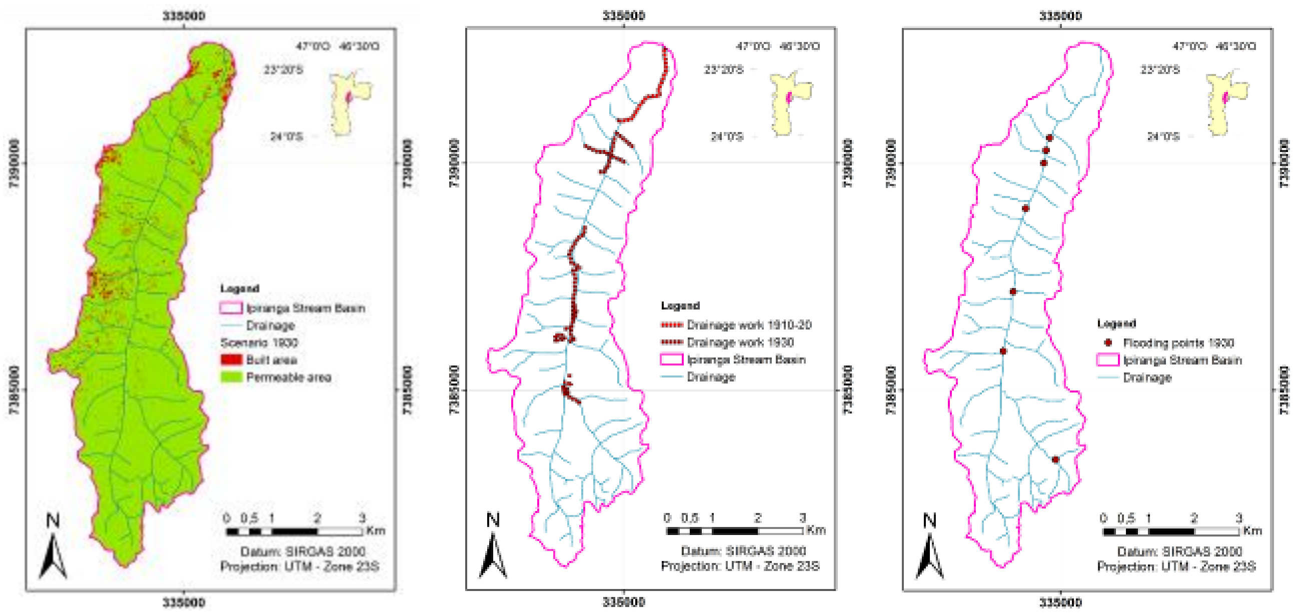
The initial situation of the multitemporal analysis is in 1930. The Mappa Topographico evaluation of the Municipality of São Paulo (SARA BRASIL, 1930) of the Basin area reveals that the urban density started in the north and northwest. Permeable areas were considered to be land without sealed surfaces, regardless of the presence of vegetation, including allotments under implementation phase (exposed soil) (Figure 7a).

Before 1930, in the period between 1910 and 1920, interventions were carried out on the stretch downstream of the main channel of the Ipiranga Stream, to enable access to the Paulista Museum (Museu do Ipiranga), an important municipal tourist spot. There were also several works on the main channel and its tributaries, in order to make it possible to occupy the middle course areas and in the upstream section for the implantation of the Botanical Garden in the Parque do Estado area (currently PEFI), with rectifications, open and closed channels (Figure 7b).

In this initial situation, areas mapped as swamps or natural water accumulations by Sara Brasil were considered as flood points. During this period, there was no occupation in the vicinity of the flooded areas (Figure 7c).

Inicial situation: 1930

Urban density	Drainage work	Flooding points
(a)	(b)	(c)



Org.: Amaral, 2019.

Figure 7 - Situation in 1930: (a) Built Area = 3.38%; Permeable Area = 96.62%; (b) Open and closed rectifications and channels. (c) Flood points, mapped as swamp areas (Sara Brasil).

Over the 32-year interval (1930 to 1962) urbanization advanced towards the south of the Basin (Figure 8a).

In the 1960s, new interventions were carried out in the watercourse, including in sections that had already been modified previously. Rectification and open channeling works were carried out on the main channel for the construction of Av. Água Funda, now called Av. Dr. Ricardo Jafet, on both banks of the stream (Figure 8b). The opening of the avenue was in 1967 and the works were completed in 1970, with part of the São Paulo Avenues Plan Program.

It is estimated that the flood points mapped on the Sara Brazil Map (1930) remained active, since, until 1962, the areas called swamp did not yet have close occupations (Figure 8c).

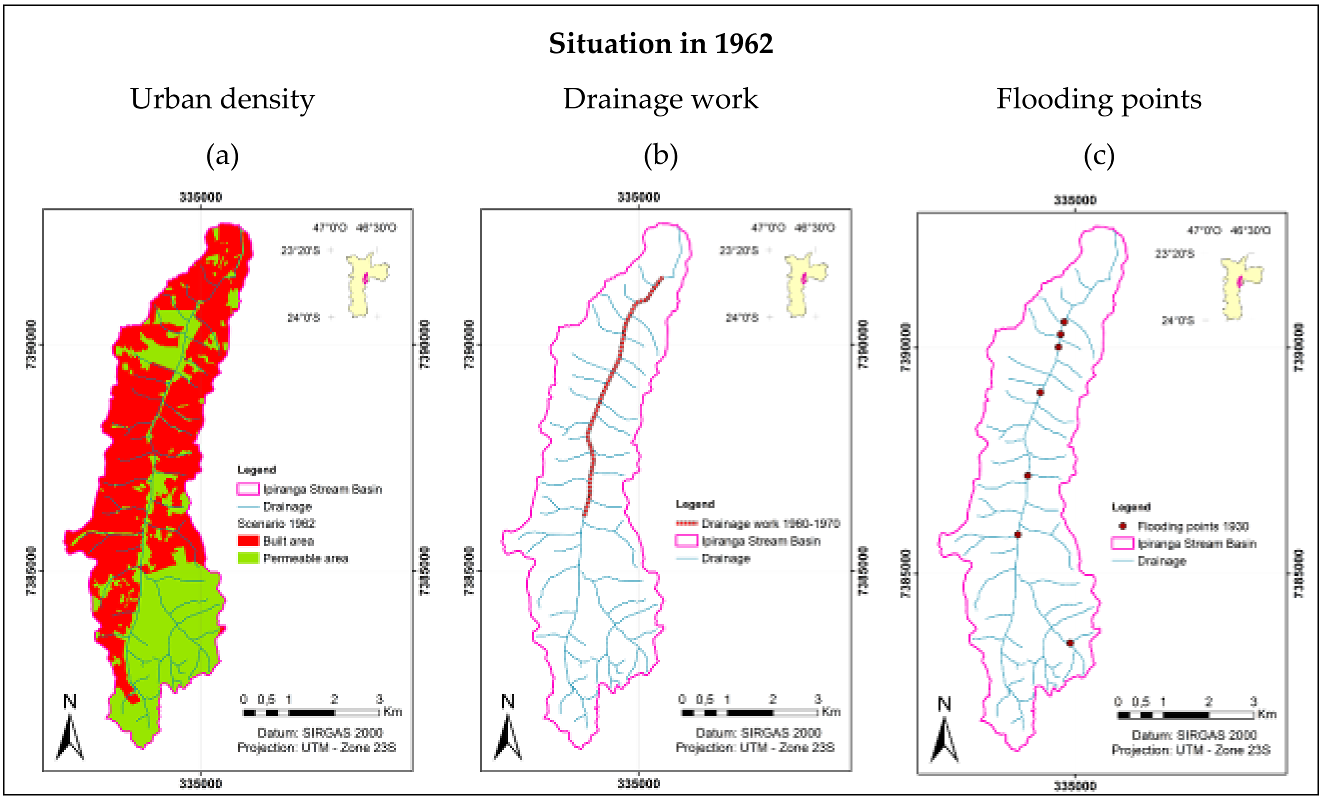


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Figure 8 - Situation in 1962: (a) Built Area = 60.23%; Permeable Area = 39.77%; (b) Beginning of the rectification and canalization works in the open over a large section of the main course. (c) Flood points remain the same as in the 1930s.

In the period between 1962 and 1994, urbanization occupies practically the entire length of the basin, leaving as permeable areas the few fragments of vegetation in areas protected by parks (such as PEFI and Parque da Independência), in areas of central flowerbeds of great avenues or in small public green areas. Since the 1990s, there has been stability in the horizontal expansion of urbanization (Figure 9a).In this period, several works were also carried out on the main channel, such as the expansion of the channel, maintenance of margins and silting in order to correct problems related to flooding in the downstream stretch, and another stretch of open channeling of the canal was carried out mainly to enable access from the avenue to the Imigrantes Highway (connection with the coast) and the underground channeling of tributaries (Figure 9b).

During period that starting in 1965, the first reports of flooding in the Ipiranga Stream and related damages are recorded. The news describes flood events in the downstream portion, which at the time had a more densely populated occupation. Between January and May 1968, 5 events were recorded, and in 4 of these events the level of water reaching homes and businesses was over 1.4 m. The news from the 1970s also reports occurrences in the downstream portion, near the mouth of the Ipiranga Stream on the Tamanduateí River. Damage was reported to about 150 homeless families and obstructed traffic for almost 12 hours, with a water level greater than 1.2 m. In the 1980s, the news still refers to floods in the downstream portion, with about 60 homeless people. The occurrences of floods were recorded at the beginning of the decade, always in the summer period. In the 1990s, the amount of news related to the floods in the Ipiranga Stream increased considerably and most of the points identified are located in the downstream portion, and one point in the middle course. In 1996 there were 4 recurrences and damage related to traffic interruption, damage to homes and industry is reported, and in one of the events around 16 thousand people were without electricity (Figure 9c).

Situation in 1994

Urban density (a) | Drainage work (b) | Flooding points (c)

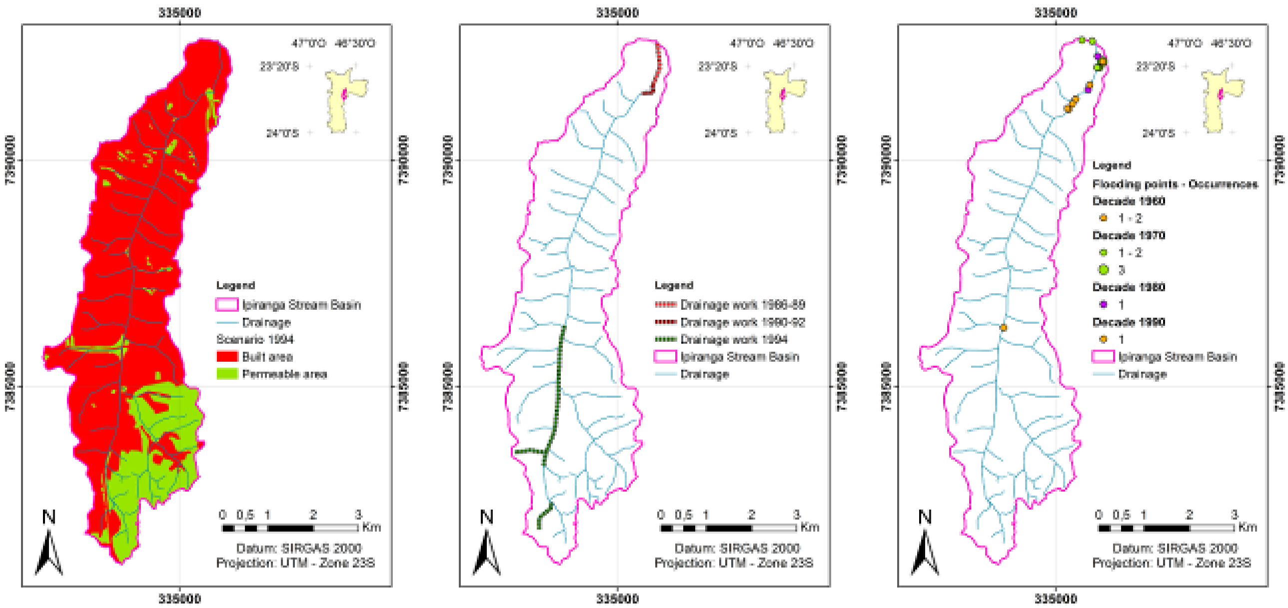

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Figure 9 - Situation in 1994: (a) Built Area = 79.44%; Permeable Area = 20.56%; (b) Expansion of the main channel, recovery of margins and reconstruction of bridges, closed tributary channels; (c) Points registered in the news, by decade and number of occurrences in each identified point.

At the end of the 1990s, land with exposed soil became rare and on a small scale. The verticalization process then started with the construction of many residential and commercial buildings, mainly in the middle course portion of the basin (Figure 10a).

During the period of 1994 to 2017, several works were also carried out on the main channel and its tributaries to correct problems related to floods, such as the expansion of the river channel, maintenance of margins, de-silting and interventions at intersections over the stream. Based on a study carried out by the City of São Paulo in 2014 and financed by the Federal Government, in

2017 the works to prevent floods in the basin began, with a project to build a temporary containment reservoir with two compartments and a storage capacity of 200 thousand m³ and de-silting of a lagoon to be transformed into a flood reservoir with a storage capacity of 100 thousand m³. It was also foreseen the expansion of the channel of the open channeled section along the middle course, which presents several points with record of recurrent floods. The completion of the works was initially scheduled for 2019 (Figure 10b).

In relation to the flood points, in addition to the news from newspapers from that period, the occurrences recorded by the CGE / PMSP, starting in 2000 and from 2007 onwards, SAISP / DAEE / FCTH data are also included. The number of occurrences continued to increase, but there were also more points of flooding in the middle course of the stream, in addition to recurring episodes in these points. The news reported one case of death, several cars dragged by the force of the water and water level reaching 2 meters high. In the decade of 2010 there was an increase in the points of flooding in the middle course, but the occurrences in the downstream points still remained. One of these points located in the middle course presented 11 occurrences in the period between 2010 and 2017. The news reports damage to homes and businesses, cars submerged and dragged by water, neighborhoods without electricity, in addition to traffic interrupted for several hours. In some events, the water level reached 1.6 m in height (Figure 10c).

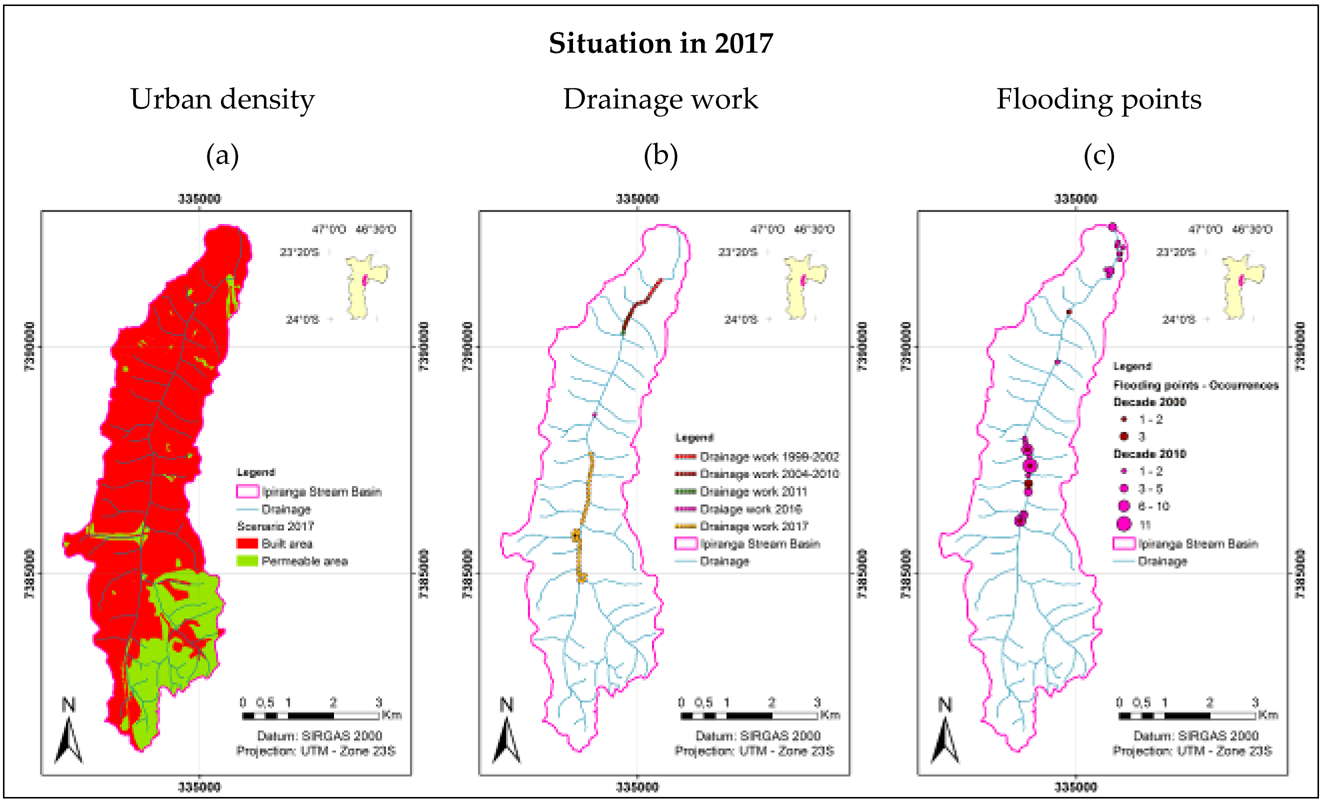

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Figure 10 - Situation in 2017: (a) Built Area = 80.39%; Permeable Area = 19.61%; (b) Maintenance of margins, construction of temporary reservoirs, de-silting and expansion of the main channel gutter; (c) Points registered in the official news and information from CGE/ PMSP and SAISP/DAEE/FCTH.

4. CONCLUSIONS

Floods in urbanized areas have social consequences that involve properties, assets and people affected, and foster the need to manage the associated risks. The problem related to urban flooding is common in most large cities. In these cases, the lack of planning for the occupation of the basins becomes evident, with the absence of measures of use restrictions in the areas of the floodplains. The other urban alterations also stand out, such as the accentuated waterproofing of the soils and the interventions in water courses, which hinder the preservation and maintenance of water resources.

The analyzed data show that despite the several drainage related works in the Ipiranga Stream Basin, in São Paulo / SP, carried out in the last century, the areas with records of flood events have remained active, and although over the years they have changed location in different stretches of the basin, the history of events found an increase in the frequency and magnitude of these events.

The increase in records of flood events in the basin in recent decades may be related to several factors, which act together, of which the following stand out:

a) The natural characteristics of the basin's morphology indicate that the elongated shape of the basin, as well as its low slope, favors the accumulation of water due to the slow flow, making the area prone to the occurrence of floods;

b) The analysis of the rainfall data reveals the tendency of increasing annual precipitation in the basin. The finding of the increase in annual totals and the occurrence of greater volumes of daily precipitation in the place, mainly above 60mm / day from the 1940s, characterizes a greater volume of water concentrated in the basin and in the main channel. It is also important to highlight the occurrence of one rainfall event higher than 120 mm/ day in each decade, recorded since the 1960s. In the municipality of São Paulo, intermittent or continuous and / or moderate to strong precipitation above 60mm already causes a state of attention and monitoring by the official departments for the potential for flooding and urban flooding. Previous studies on changes in the annual amount and distribution of precipitation in the Ipiranga Stream basin, as well as other studies that discussed the characteristics of urbanized areas, evaluate that the causes of these changes may be due to urbanization and heat islands effect, or they may have a regional or global climatic cause;

c) The greater transmission of news by the media may be due to the impact of floods on the dynamics of circulation and the local economy. The history of events collected data from consultations with digital information media (newspapers) and official sources (CGE / PMSP and SAISP / DAEE / FCTH) and in total 82 flood events were recorded in the basin between 1965 and 2017, more than half (46 events) were recorded between 2010 and 2017. Official sources (CGE and SAISP) provided specific and detailed data for the basin, although some of these events were also reported in the newspapers. It is noteworthy that this information was incorporated into the history from the beginning of its operation, in 2000 and 2007, respectively;

d) The expansion of soil waterproofing rates influences directly on runoff. In the 1930s, the built areas represented only 3.38% of the total area of the basin; in 1962, the built areas already reached 60% of the total basin. They evolved to 79% in 1994 and to 80% in 2017, when they showed stagnation. These characteristics changed the permeability of soils and, consequently, the dynamics of runoff in the basin over the analyzed period;

e) As verified in history, to make the occupation of the basin viable, changes in the watercourse, in several channels and rectifications in the main channel and in the tributaries were made. These modifications allowed the displacement of the flood points identified over time. As a particular stretch of land was subject to construction, other portions of the previously unscathed plain began to experience flooding events.

Based on the integrated assessment of natural and man-made factors, there is a growing tendency for flooding phenomena at the site, in case interventions that give greater importance to local characteristics are not made.

In this case, flood-fighting projects should opt for the conservation of lowland areas, such as, for example, the construction of a linear park along the main course. Studies carried out by the Municipality of São Paulo evaluated that due to the fact that the basin already has a consolidated occupation on the banks of the Ipiranga Stream and the Avenues Dr. Ricardo Jafet and Prof. Abraão de Morais, the alternative of building the linear park was not viable due to the high cost of expropriations and reallocations, in addition to problems related to land issues. However, over the past 30 years, approximately $ 400 million has been invested in works and the floods continue to cause damage and risks to the population and traffic on the site.

Structural works to contain floods, which are part of the genesis of river plains, have not shown satisfactory and permanent results. In these works, as has been indicated throughout recent history, it has always been a priority to facilitate the flow of water, through rectifications, enlargements and deepening of the channels, promoting changes in the locations of chronic floods. Temporary rainwater retention solutions, through the construction of large reservoirs, were not sufficient to contain flooding during times of heavy daily or even hourly rainfall. In view of this, small works along the basin should be prioritized with the objective of temporary retention through public and private micro reservoirs with the aim of promoting the retardation of runoff water flows throughout the entire basin.

Thus, it is considered that addittional measures can be used concurrently with structural measures already in progress, such as the implantation of some points of temporary water accumulation, such as retention systems in the slopes - for example, rain gardens or the implantation of permeable pavements - in the middle course to the downstream section. These measures do not need large extensions of continuous areas, require little investment to be implemented and can minimize economic, environmental and social problems.

It also highlights the importance of making awareness effort on how to live with risk so that they can avoid further loss of life and property.

References

Amaral, R. ve Ribeiro, R.R. (2009). Inundações e enchentes. In: Tominaga, L. K., Santoro, J. ve Amaral, R. (Orgs.) *Desastres naturais: conhecer para prevenir*. 1ª edição, São Paulo: Instituto Geológico, p. 39-52.

Anelli, R. L. S. (2015). Uma nova cidade para as águas urbanas. *Estudos Avançados* 29 (84), DOI: https://doi.org/10.1590/S0103-40142015000200005 /

Bertrand, G. (1971) Paisagem e Geografia Física Global – Esboço Metodológico. *Caderno de Ciências da Terra*, 13. São Paulo: Instituto de Geografia – Universidade de São Paulo.

Boudou, M., Danière, B. ve Lang, M. (2016). Assessing changes on urban flood vulnerability through mapping land use from historical information. *Hydrology and Earth System Sciences*, v. 12, p. 161-173, 2016. DOI 10.5194/hess-20-161-2016.

Carvalho, C. S., Macedo, E. D. ve Ogura, A. T. (2007). *Mapeamento de riscos em encostas e margem de rios.* Brasília: Ministério das Cidades.

Cœur, D. ve Lang, M. (2008). Use of documentary sources on past flood events for flood risk management and land planning. *Comptes Rendus Geoscience*, v. 340(9), p. 644-650, DOI 10.1016/j.crte.2008.03.001.

Cooke, R.U. ve Doornkamp, J.C. (1990). *Geomorphology in Environmental Management*: *A New Introduction*, Clarendon Press, Oxford.

Custódio, V. (2002). *A persistência das inundações na Grande São Paulo.* Tese de Doutorado, Departamento de Geografia, FFLCH, Universidade de São Paulo.

DAEE - Departamento de Águas e Energia Elétrica (2011). Elaboração do Terceiro Plano Diretor de Macrodrenagem da Bacia do Alto Tietê – PDMAT3, *Relatório nº 1 – PTC – Plano de Trabalho Consolidado.* DAEE. Available in: http://www.daee.sp.gov.br/index.php?option=com_contentveview=articleveid=1364veItemid=7.

DAEE - Departamento de Águas e Energia Elétrica (2012). *Terceiro Plano Diretor de Macrodrenagem da Bacia do Alto Tietê – PDMAT3, Parte II, Tomo I – Levantamentos Gerais e Levantamento e Mapeamento das Áreas de Risco Conhecidas.* DAEE. Available in: http://www.daee.sp.gov.br/index.php?option=com_contentveview=articleveid=1364veItemid=7.

EMPLASA – Empresa Paulista de Planejamento Metropolitano (1980-81). Folhas planialtimétricas do Sistema Cartográfico Metropolitano.

FABHAT - Fundação Agência da Bacia Hidrográfica do Alto Tietê (2016). *Relatório – I - Plano de Bacia Hidrográfica do Alto Tietê - UGRHI 06*, Ano Base 2016/2035. FABHAT. Available in: http://www.sigrh.sp.gov.br/public/uploads/documents/CBH-AT/11958/relatorio-i_plano_final-rev2.pdf

Faccini, F., Luino, F., Sacchini, A., Turconi, L. ve De Graff, J.V. (2015). Geohydrological hazards and urban development in the Mediterranean area: an example from Genoa (Liguria, Italy). *Natural Hazards Earth System Sciences*, v. 15, p. 2631-2652. DOI 10.5194/nhess-15-2631-2015.

Faccini, F., Paliaga, G., Piana, P., Sacchini, A. ve Watkins, C. (2016). The Bisagno stream catchment (Genoa, Italy) and its major floods: geomorphic and land use variations in the last three centuries. *Geomorphology*, v. 273, p. 14-27. DOI 10.1016/j.geomorph.2016.07.037.

Fernandes da Silva, P. C., Andrade, E. ve Rossini-Penteado, D. (2014). Mapeamento de perigos e riscos de inundação: uma abordagem semiquantitativa. *Revista do Instituto Geológico*, São Paulo, v. 35, n. 2, p. 13-38.

Ferreira, J.B. ve Amaral, R. (2017). Análise dos dados pluviométricos da bacia hidrográfica do Córrego Ipiranga, São Paulo/SP, In: *Caderno de Resumos do 7º Seminário de Iniciação Científica PIBIC-IG*, São Paulo: Instituto Geológico. Available in: http://igeologico.sp.gov.br/files/2018/02/RESUMOS_7-SIC-IG_2016.pdf

Goudie, A. (1994). *The human impact on the natural environment*, Ed. MIT Press, Great Britain.

Guerra, A. J. T. ve Marçal, M. S. (2006). *Geomorfologia ambiental.* Rio de Janeiro: Bertrand Brasil.

Gutjahr, M. R., Rabello, J. F. D., Gomes, M. L. F. ve Jesus, M. H. S. (2010). Estudos históricos de eventos climáticos extremos na Baixada Santista- SP Brasil. In: *VI Seminário Latino-Americano de Geografia Física II Seminário Ibero-Americano de Geografia Física Universidade de Coimbra*.

Horton, R. E. (1945). Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological society of America bulletin*, v. 56, n. 3, p. 275-370.

IAG – USP – Instituto de Astronomia, Geofísica e Ciências Atmosféricas da Universidade de São Paulo (2016). Boletim Climatológico Anual da Estação Meteorológica do IAG/USP, Seção Técnica de Serviços Meteorológicos, v. 19. São Paulo: IAG/USP.

IG - Instituto Geológico (2009). Banco de Dados Históricos de Desastres Naturais Relacionados a Eventos Climáticos na Baixada Santista. Available in: http://200.144.28.233/dnbs/busca.php.

Kanashiro, W. H. (2013). Uma nova proposta para a macrodrenagem do Rio Tietê. In: *Revista Engenharia nº 613*, p. 80-85. Available in: https://issuu.com/www.viapapel.com.br/docs/613_baixa

Kochel, R. C. (1988). Geomorphic impact of large floods: review and new perspectives on magnitude and frequency. *Flood Geomorphology.* John Wiley ve Sons New York. p 169-187.

Leopold, L., Wolman, M.G. ve Miller, J.P. (1964). *Fluvial processes in Geomorphology.* San Francisco: W.H. Freeman and Co.

Luz, R. A. (2010). *Geomorfologia da planície fluvial do rio Pinheiros entre os bairros de Pinheiros, Butantã e Cidade Jardim, São Paulo (SP).* Tese de Doutorado. Universidade de São Paulo.

Monteiro, C. A. F. (1973). *A Dinâmica Climática e as Chuvas no Estado de São Paulo: estudo geográfico sob a forma de atlas.* Instituto de Geografia.

Monteiro, C. A. F. (2000). *Geossistemas – a história de uma procura.* São Paulo: Contexto.

Moroz – Caccia Gouveia, I. C. (2010). *Da originalidade do sítio urbano de São Paulo às formas antrópicas: aplicação da abordagem da Geomorfologia Antropogênica na Bacia Hidrográfica do Rio Tamanduateí, na Região Metropolitana de São Paulo.* Tese de Doutorado, Departamento de Geografia, FFLCH, Universidade de São Paulo.

PMSP - Prefeitura da Cidade de São Paulo (2017). Mapa Digital da Cidade de São Paulo. Available in: http://geosampa.prefeitura.sp.gov.br/PaginasPublicas/_SBC.aspx.

Rodrigues, C. (1997). *Geomorfologia Aplicada: Avaliação de experiências e de instrumentos de planejamento físico-territorial e ambiental brasileiros.* São Paulo, Universidade de São Paulo. Tese de Doutorado.

Rodrigues, C. (2005). Morfologia original e morfologia antropogênica na definição de unidades espaciais de planejamento urbano: exemplo na metrópole paulista. *Revista do Departamento de Geografia*, v. 17, p. 101-111.

Rodrigues, C. (2015). Atributos ambientais no ordenamento territorial urbano. O exemplo das planícies fluviais na Metrópole de São Paulo. *GEOUSP Espaço E Tempo (Online)*, v. 19, n. 2, p. 324-347. Available in: https://www.revistas.usp.br/geousp/article/view/102805

Rolnik, R. (1999). Lei e Política: a construção dos territórios urbanos. *Projeto História: Revista do Programa de Estudos Pós-Graduados de História*, v. 18.

Ross, J. L. S. (1992.) O registro cartográfico dos fatos geomórficos e a questão da taxonomia do relevo. *Revista do Departamento de Geografia*/FFLCH/USP, n.º 6, p. 17-29.

Ross, J. L. S. (1994). Análise empírica da fragilidade dos ambientes naturais e antropizados. *Revista do Departamento de Geografia*/FFLCH/USP, n.º 8, p. 63-73.

Salvadore, E., Bronders, J. ve Batelaan, O. (2015). Hydrological modelling of urbanized catchments: A review and future directions, *Journal of Hydrology*, v. 529 (1), p. 62-81. DOI 10.1016/j.jhydrol.2015.06.028.

Santos, A. P. ve Amaral, R. (2017). Levantamento histórico de dados de inundação do córrego Ipiranga – São Paulo/SP, In: *Caderno de Resumos do 7º Seminário de Iniciação Cientifica PIBIC.* São Paulo: Instituto Geológico. Available in: http://igeologico.sp.gov.br/files/2018/02/RESUMOS_7-SIC-IG_2016.pdf

Sara Brasil (1930). *Mappa Topographico do Município de São Paulo*.

Seabra, O. C. D. L. (1987). *Os meandros dos rios nos meandros do poder: Tietê e Pinheiros–valorização dos rios e das várzeas na cidade de São Paulo.* Tese de Doutorado. São Paulo: USP/FFLCH.

Sotchava, V. B. (1978). Por Uma Teoria de Classificação de Geossistemas da Vida Terrestre. In: *Biogeografia* nº 14. São Paulo: Instituto de Geografia – Universidade de São Paulo.

Strahler, A.N. (1957). Quantitative analysis of watershed geomorphology. Eos, *Transactions American Geophysical Union*, v. 38, n. 6, p. 913-920.

Swiss Re Institute (2018). Natural catastrophes and man-made disasters in 2017: a year of record-breaking losses. Available in: https://www.swissre.com/institute/research/sigma-research/sigma-2018-01.html

Szabó, J., Dávid, L. ve Lóczy, D. (2010). *Anthropogenic Geomorphology – A Guide to Man-Made Landforms*. New York: Springer.

Tavares, A.C, Silva, A.C.F. (2008). Urbanização, chuvas de verão e inundações: uma análise episódica. *Climatologia e Estudos da Paisagem.* Rio Claro. v. 3, n.1.

Travassos, L. R. F. C. (2004). *A dimensão socioambiental da ocupação dos fundos de vale urbanos no Município de São Paulo.* Dissertação de Mestrado. Programa de Pós-Graduação em Ciência Ambiental da USP (PROCAM/USP). São Paulo: PROCAM.

Tricart, J. (1977). *Ecodinâmica.* Rio de Janeiro: FIBGE, Secretaria de Planejamento da Presidência da República.

Ward, R. (1978). *Floods, A Geographical Perspective.* Macmillan Press, London.

Xavier, T. M. B. S., Xavier, A. F. S. ve Dias, M. A. F. D. S. (1994). Evolução da precipitação diária num ambiente urbano: o caso da cidade de São Paulo. *Revista Brasileira de Meteorologia*, v. 9(1), p. 44-53.

Zăvoianu, I. (1985). Morphometry of drainage basins. *Developments in water Science*, 20, Elsevier.

Zilli, M. T., Carvalho, L., Liebmann, B. ve Silva Dias, M. A. (2017). A comprehensive analysis of trends in extreme precipitation over southeastern coast of Brazil. *International Journal of Climatology*, v. 37(5), p. 2269-2279. DOI 10.1002/joc.4840.