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The impact of land use/land cover change in suburban subdivisions on surface runoff: the case of the Gated Community Alto da Boa Vista (Federal District, Brazil)

O impacto do parcelamento de solo sobre o escoamento superficial: o caso do Condomínio Alto da Boa Vista (Distrito Federal, Brasil)

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ABSTRACT: Environmental damages are inherent to urbanization processes and therefore need to be carefully measured and mitigated, especially those that affect hydrological regimes, because they reverberate beyond the urbanized area and reach the entire watershed. Although essential for mitigating environmental damages affecting suburban subdivisions, drainage systems and rainwater management are usually given secondary status during urban land planning. The present study evaluated the implications of the absence of adequate subdivision planning, focusing on the process of occupation and regularization of the Gated Community Alto da Boa Vista – in the *Sobradinho* Administrative District (in Brazil's Federal District). Our sources were land regularization documents, data on rainfall, soil typology and remote sensing imagery. The images allowed us to detect changes in soil cover over several years and to identify resulting changes in infiltration and runoff. Data analysis showed that faulty attention was given to environmental and urban aspects during the planning phase and the installation of the gated community and contributed to the occurrence of erosion processes. It was found that it is necessary to improve public management routines to expedite the granting of urban and environmental licenses, in addition to defining technically adequate and integrated requirements for the installation of drainage systems and the management of rainwater runoff in areas affected by urban expansion.

Keywords: land tenure regularization; environmental deterioration; subdivision impacts; catchment hydrology; urban planning.

RESUMO: Danos ambientais são inerentes ao processo de urbanização e por isso devem ser meticulosamente mensurados e mitigados, especialmente aqueles que afetam o regime hidrológico, pois os seus efeitos reverberam para além da área urbanizada e atingem toda a bacia hidrográfica. Embora essenciais para a mitigação dos danos ambientais de parcelamentos urbanos, os sistemas de drenagem e manejo de águas pluviais são tipicamente relegados ao segundo plano no decurso da regularização fundiária urbana. O presente estudo avaliou as implicações da ausência de planejamento adequado, focalizando o processo de ocupação e regularização do Condomínio Alto da Boa Vista – Sobradinho (Distrito Federal). As fontes usadas foram a documentação de regularização fundiária, dados relativos ao regime pluvial, tipologia dos solos e imagens de sensores remotos. As imagens possibilitaram detectar mudanças na cobertura do solo ao longo de vários anos e identificar alterações decorrentes da infiltração e do escoamento superficial. A análise evidenciou que as irregularidades ambientais e urbanísticas ocorreram durante o processo de planejamento e instalação do parcelamento e contribuíram para a ocorrência de fenômenos erosivos. Constatamos que é necessário aperfeiçoar a gestão pública no sentido de extinguir a morosidade na concessão de licenças urbanísticas e ambientais, além de definir previamente exigências tecnicamente adequadas e integradas para a instalação de sistemas de drenagem e manejo de águas pluviais em áreas de expansão urbana.

Palavras-chave: regularização fundiária; degradação ambiental; urbanização; sistema de captação de águas pluviais; planejamento urbano.

1. Introduction

Traditionally, the process of urban expansion occurs to meet human needs for housing, commerce, production, integration, and leisure. As a rule, human needs and interests in occupying certain spaces precede concerns about the environmental suitability of these soon to be occupied spaces. This has stimulated the development of technologies that seek to neutralize environmental "inconveniences" that disturb the establishment of settlements.

In the context of urban occupation and expansion, the first natural components of the landscape to be sacrificed are bodies of water or humid areas – rivers, lakes, their embankments, floodplains, mangroves, sandbanks, springs, and aquifers. Hence, urbanization generates enormous problems related mainly to the deterioration of natural and urban environments. This leads to processes of social disorganization, like scarce and precarious housing, unemployment, and problems with basic sanitation. Solutions of these problems typically depends on government interventions (Silva, 2018). Governments will seek to care for urban environments and seek to create better conditions for human occupation through **urbanification**, a deliberate process of correcting the flaws of poorly planned urbanization. However, correction efforts by public authorities sometimes explicitly and admittedly promote further problems and urban disarray.

Urban explosion and the lack or scarcity of investments in urbanification have led to many episodes of deterioration of living conditions. New forms of government action are needed to promote more efficient housing programs. These programs must seek the quality desired by the population and follow accepted standards of habitability (Fantinatti & Zuffo, 2011). Among minimum habitability requirements is the installation of basic sanitation infrastructure. In Brazil, however, according to the 2017 National Survey of Basic Sanitation (IBGE, 2017), 99.6% of municipalities were linked to water supply services, but only 60.3% of them were served by sewage services in collection networks. The survey does not even contain data regarding drainage and rainwater management and solid waste collection systems.

The IBGE survey and its gaps demonstrate the general ack of sanitation infrastructure related to sewage collection and treatment, rainwater management, and solid waste management. These deficiencies precisely affect the aspects of sanitation that are most relevant for mitigating environmental damage resulting from unplanned urbanization. This context reinforces the evidence that the environmental dimensions of urbanization are disregarded in the prevailing modes of land occupation in Brazilian cities. Among other aspects, this has contributed to imbalanced water cycles – both in terms of runoff and infiltration (Bezerra *et al*., 2020).

Rainwater runoff problems are not new to decision makers entrusted with regulating local land use. The main concern with runoff has always been safety, leading to a focus on directing and draining water from paved surfaces as quickly and efficiently as possible. Once off the streets and sidewalks and out of sight, rainwater is largely forgotten – regardless of downstream consequences (Arnold & Gibbons, 1996). This results in flooding, rivulets, ponding, erosion, siltation, and water contamination, that is, social and environmental problems arising from the lack of planning the occupation of urban basins. Although essential to environmental preservation, rainwater drainage and management are not thoroughly explored in federal environmental or urban regulations.

One of the few regulations that deals with rainwater drainage is the Federal Basic Sanitation Policy, established by Law No. 11,445, of January 5, 2007 (Brasil, 2007). However, it approaches the topic in a generic manner and does not define implementation principles.

Given the need to minimize environmental and social risks inherent to urban expansion, the scientific literature has been reconstructing the theory, execution and management of rainwater systems. In the novel approach adopted as reference for this article, control and minimization of the adverse effects of floods, inundations and ponding in urban areas goes beyond the dominant notion of the traditional technical priority - the removal of rainwater flow from critical points (Christofidis *et al.*, 2019).

In other words, the concept of drainage and rainwater management systems has advanced in a new direction, highlighted by authors such as Righetto (2009) and Tucci et al. (2002). According to these authors, systems are now conceived as a set of actions and solutions that are both structural and non-structural, involving the execution of large and small construction plans and the management of urban space occupation. Urbanization experiences demonstrate that conventional water resource engineering practices often exacerbate downstream flooding. Furthermore, they degrade water quality, destroy habitats, and compromise the stability of systems due to the accumulated volume and speed of discharge flows (Farr, 2013). Pompêo (2000) maintains that the planning of urban activities in connection with water must be integrated into the the wider scope of urban planning itself, including the design of the urban network and its expected expansion, zoning of activities, street and transportation network, information flows, aspects of the landscape etc.

Hence, drainage system design is not to be restricted to the planning of a collection network that transfers surface runoff from a surface of interest to a different release point, ignoring further environmental impacts. Rainwater management needs to adopt principles that include water dynamics in the hydrological cycle. These principles should reduce rainwater surface runoff and induce infiltration and percolation in the soil to achieve quantitative, qualitative, and control of the water flow. The management system must also adopt water retention structures, as alternative equipment designed to reduce flood peak and water flow speed (Souza et al., 2012).

Due to the implications of the lack of adequate planning, this article aims to examine:

(i) how did the occupation process of the Gated Community Alto da Boa Vista – Planaltina/DF occur; and

(ii) environmental modifications resulting from changes in land use at the community site.

Our analysis correlated changes in surface runoff as a result of urban occupation of the area, considering both the physical installation of the subdivision and the land tenure procedures that supported the registration and regularization of the gated community.

2. The study area

The Gated Community Alto da Boa Vista, located in Brazil's Federal District – is located close to a consolidated urban area (Figure 1). According to the Federal District Territorial Plan – PDOT/DF, the community is located in the Urban Expansion and Qualification Zone (Distrito Federal, 2009).

This new urban subdivision was designed in the format of a multiple-use, gated community. With an area of 251.83 hectares, the project planned to build 2,705 residential and multiple-use units and 141 commercial units (Distrito Federal, 2022). Although, according to PDOT/DF, the entire area is located in an Urban Expansion and Qualification Zone, part of the land has features that do not allow urban uses. It has two springs that flow into the Sobradinho River, represented by the "watercourse" present in Figure 1. This means that part of the community is classified as a Permanent Preservation Area (*Área de Proteção Permanente*, or APP). Furthermore, the terrain has a steep slope compared to the mostly level or gently waving areas of the Federal District.[1] The slope is evident from the shape and proximity of the contour lines shown in yellow in Figure 1. This steep slope on the Eastern part of the terrain and the two springs are relevant factors for the analysis of the urban conversion process caused by the installation of the gated community.

3. Materials and methods

Our analysis of the effects of converting the area from rural to urban uses divided it into three sections, based on:

(i) slopes recorded by contour lines at a scale of 1:5,000 (IDE/DF, 2022);

(ii) rainwater drainage basins (Distrito Federal, 2022); and

[1] APPs are defined by Brazil's forest legislation as a variable stretches of any rural or urban property in which springs and rivulets and/or stretches with steep slopes. Landowners are supposed to mark out these areas and use them only for "sustainable" activities.

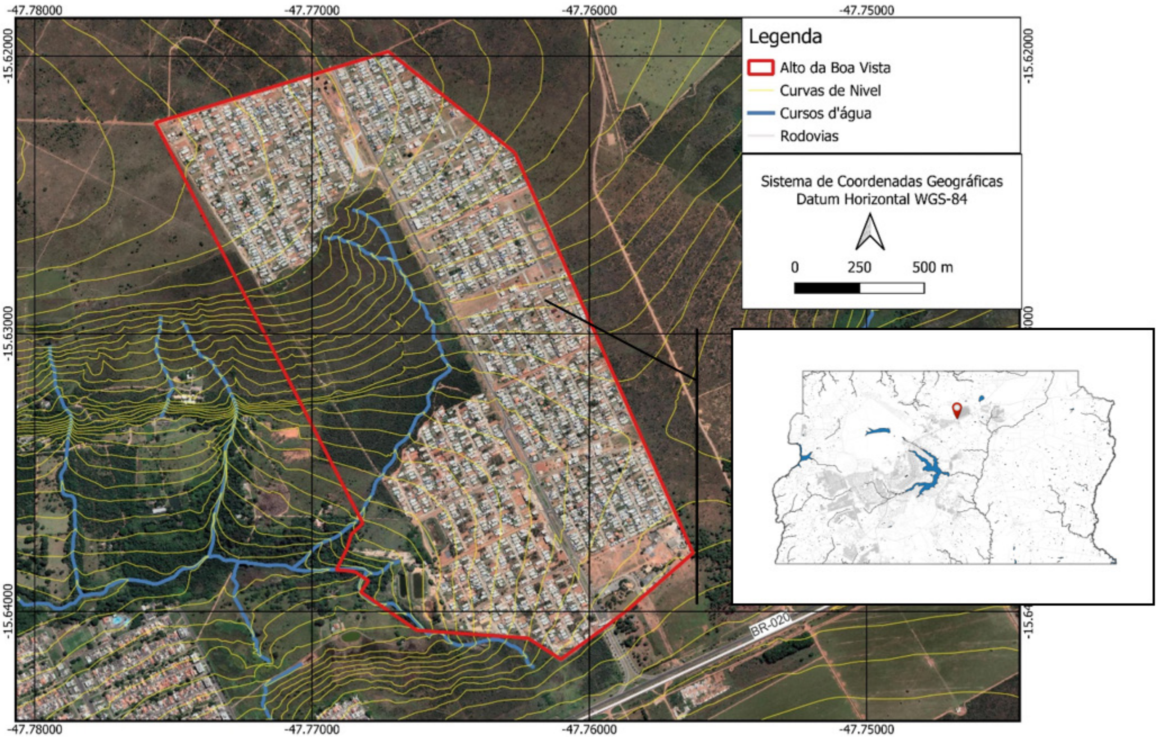

FIGURE 1 - Location of the Gated Community Alto da Boa Vista, in Planaltina, Federal District.
SOURCE: Produced by the Authors, based on *Google Earth* (2022); IDE/DF (2022).

(iii) the temporal sequence of implementation of individual plots and infrastructural features. This division is shown in Figure 2.

Area 1is located in the Northwestern portion of the subdivision. Its conversion to urban land happened at the very beginning of the operation, between 2005 and 2007. The effectively occupied part of the section has a less steep topography than the rest of the terrain, which contains the Permanent Preservation Area of the gated community. Area 2 is in the northeast portion of the subdivision; its conversion into urban land also occurred early in the installation of the project. Finally, Area 3 covers the entire South side of the subdivision; the developer completed the street network of this portion only in 2015.

We used QGis software as a working platform to subdivide contribution basins and display the physical characteristics of the study area. We measured the surfaces on which changes in land cover occurred for the years 2002, 2007, 2009, 2012, 2015, 2017, and 2022. These changes resulted from the main conversion events, such as opening roads and demarcating and building plots.

The next step consisted of determining infiltration and runoff behavior in each area. For this, we

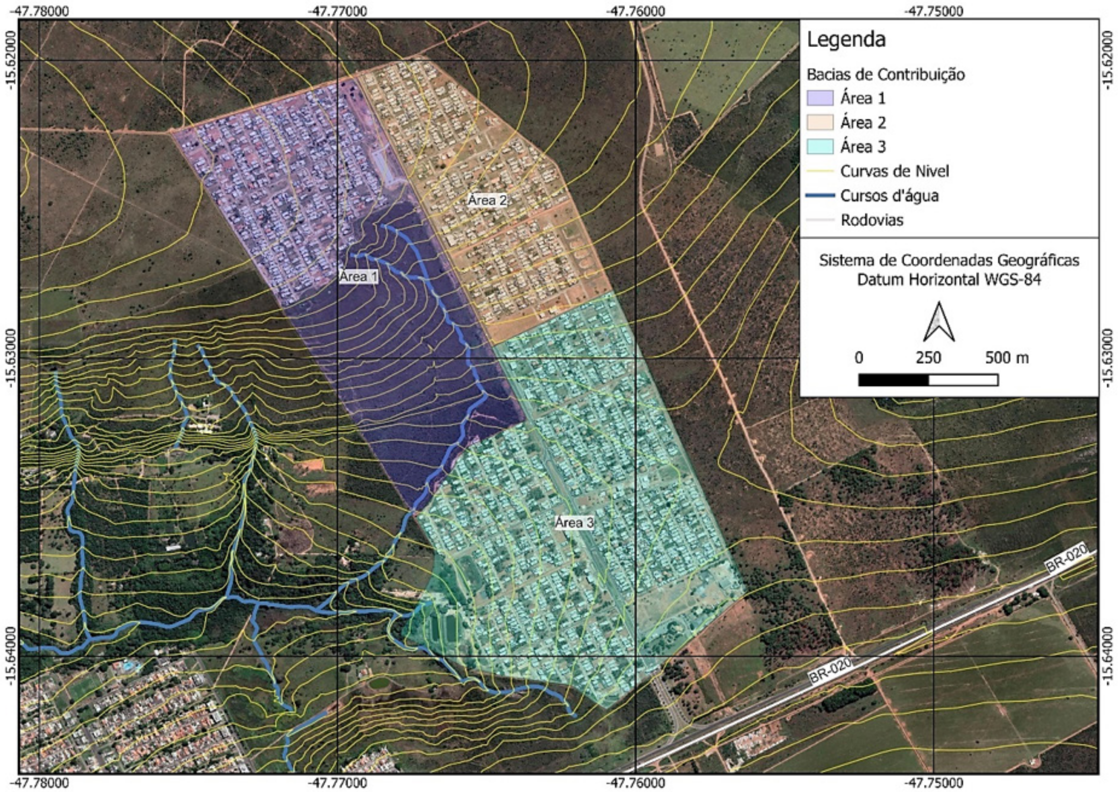

FIGURE 2 - The three sections of the Gated Community Alto da Boa Vista which contribute to the flow of runoff and to water infiltration.
SOURCE: Produced by the Authors, based on *Google Earth* (2022); IDE/DF (2022).

used ABC 6 software, developed by the Laboratory of Decisions Support Systems (LabSid) of the Polytechnical School of the Universidade de São Paulo (POLI-USP). ABC 6 is used to simulate rain related events in urban watersheds and in small rural basins. It consists of a synthetic model with parameters adjusted according to the physical characteristics of each watershed. We estimated infiltration and surface runoff directly from the project area, adopting a discrete interval for 10-minute estimations. ABC 6 provides different equations to compute water concentration time in each studied section, i. e. the time water takes to flow from the furthest point of the basin to the study section. We used the Soil Conservation Service - SCS formula to determine the concentration time of the basin, applicable to basins of up to 8 km² whose concentration time is sensitive to the value of the curve number.[2]

[2] The Curve Number (CN) method developed by the Soil Conservation Service – USA is a simple method based on soil texture, land use and occupation, and soil conservation practices adopted in the basin. The method seeks to determine the approximate volume of surface runoff from a rain event in a given region.

To define the curve number, we considered land use and occupation for each contributing basin, applying curve number values referring to roads, urban plots, and vegetation. Curve number values were fed into the software, taking into account the occupation characteristics, such as the physiognomy of the vegetation (dense or sparse) or road coverage (paved or dirt).

ABC 6 generated graphs representing total precipitation and excess precipitation in the form of hyetographs of direct surface runoff that reflect the changing behaviors occurring in the environment. We used land cover data for 2002, 2009, 2015, 2017, and 2022 to analyze runoff.

In the second stage, we gathered information regarding the process of urban and environmental regularization of the study area – licenses, descriptive reports, surveys, studies, and projects used in the long process of land regularization.

Finally, we added data obtained through a survey with an unmanned aerial vehicle – VANT, model Phantom 4 PRO V2.0 COM SENSOR CMOS of 1” and 20 MP, which provided detailed images of erosive processes.

4. Results

4.1. The expansion of waterproof soils in the Gated Community Alto da Boa Vista

Waterproof surfaces are those covered by any type of material that prevents water infiltration in the soil. Waterproofing generates significant environmental concerns, since urban water flows are closely associated with degradation of urban areas (Arnold & Gibbons, 1996; Ebrahimian et *al.*, 2016).

Waterproofing is an intrinsic characteristic of urbanization, damaging the natural capacity for water infiltration in the soil and increasing the volume of superficial runoff. Consequences build up as increased maximum flow rates, floods and landslides, decreased quality in superficial and underground water, and silting (Tucci, 2012).

Over a period of 20 years, 73% of the area of the gated community became extensively waterproofed. First, road construction to delimit predominantly residential plots caused progressive land conversion from rural to urban use. In 2017, plot occupation was intensified with the construction of new roads and buildings, culminating in the full urbanization of the project area – Figure 3(a).

The waterproofed area increased the most between 2017 and 2022, when the developers waterproofed 34% of the total contributing area. However, reduction in infiltration was more pronounced in the initial stage of the project (2002 - 2012), with street paving, removal of native vegetation, and commercial planting of tree species – Figure 3 (b).

Figure 4 shows the situation of the area in 2002. At that time, the area had plots of commercial tree plantations, unpaved access roads, and native vegetation. Land cover in 2002 resulted in hyetograms with lower excess precipitation – Figure 4 (a), (b), and (c) – represented in the red portion in the hyetogram columns.

From 2009 onwards, we identified the first impacts of changes in land cover on the reduction of infiltration rates. After the opening of roads and the removal of commercial tree plantations, the soil of approximately 14% of the studied area became waterproof, due to the construction of access roads

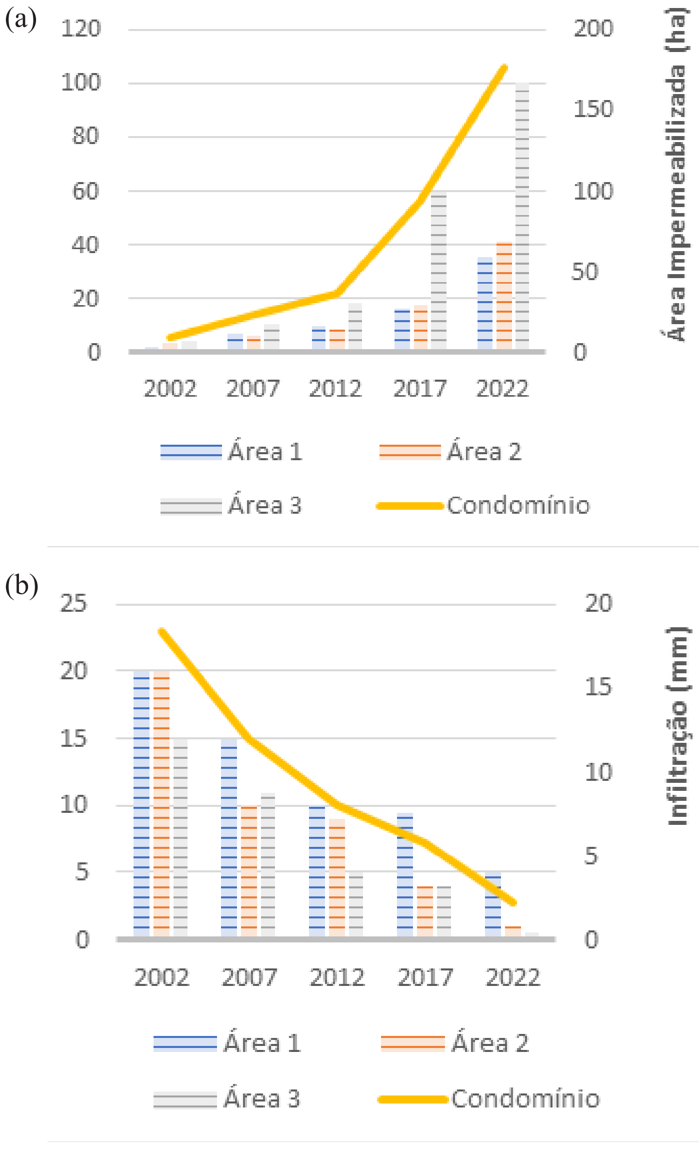

FIGURE 3 - (a) Evolution of the total waterproofed area, in hectares, in the Gated Community Alto da Boa Vista from 2002 to 2022. (b) Infiltration behavior, in millimeters, considering maximum precipitation values for the Gated Community Alto da Boa Vista from 2002 to 2022.
SOURCE: Produced by the Authors.

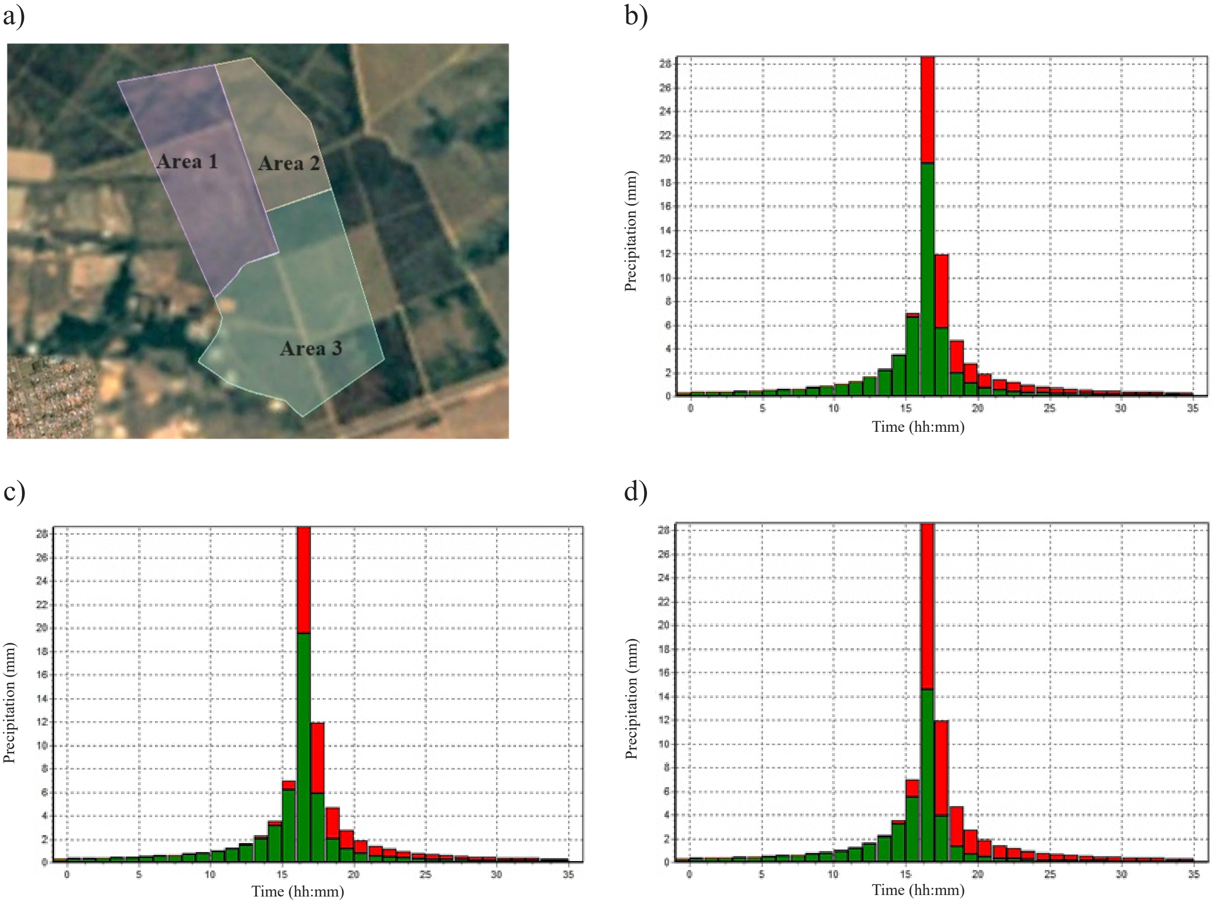

FIGURE 4 - (a) Effects of subdivision and precipitation in the three areas of Gated Community Alto da Boa Vista (2002). Surplus rainfall hyetograms for the year 2002 for Area 1 (b), Area 2 (c), and Area 3 (d) with infiltration values in green and runoff in red.

SOURCE: Produced by the Authors, based on *Google Earth* (2023).

and plot occupation. This generated the growth of excess rain, as recorded in hyetograms of Areas 1, 2, and 3 – Figure 5 (a), (b), and (c).

If we compare Figure 4 with Figure 5 we see that peak excess rainfall values in Areas 1 and 2 grew, respectively, 112 and 125% between 2002 and 2009. The same decline in infiltration in the period occurred to a lesser extent in Area 3, where peak excess rainfall increased by 30%. The difference between the peak surplus values of the areas is explained by land cover in 2002: Areas 1 and 2 had native vegetation and commercial tree plantations, which allowed higher soil permeability, while Area 3 had no floral cover, as it was under a fallow regime. The sharp change in water surplus values demonstrates the decisive factors in the reduction of soil infiltration: installation of roads, removal of commercial tree coverage, and cutting of native vegetation.

In 2015, the project's roads were completed, together with the occupation of the entire Area 3 and the expansion of Area 1 to the limits of the community's Permanent Preservation Area. Furthermore, between 2009 and 2015, plots still occupied by fallow land or native vegetation were converted into buildings, resulting in the waterproofing of 53% of the project by roads and buildings, as shown in Figure 6(a).

In addition to road construction, Area 3 removed an additional portion of its vegetation cover between 2012 and 2015 to allow the construction of multiple-use buildings and equipment, leading to a more pronounced reduction in infiltration. Growth in excess precipitation values can be seen when comparing Figures Figure 4 (d), Figure 5 (d), Figure 6 (d) and Figure 7 (d).

Area 3 has some special traits related to the construction of its infrastructure. Part of the area lies below the Permanent Preservation Area, next to the steepest slopes. Road construction in this location took place between 2009 and 2015. Unlike Areas 1 and 2, where developers built most roads in 2004 as unpaved streets, roads in Area 3 were built and quickly paved. This caused an abrupt change in the speed of rainwater runoff flow, reduction in infiltration, and increase in surface runoff, as recorded in Figure 7 (d).

Between 2017 and 2022, with the completion of the project, the infiltrated portion of precipitation in Areas 2 and 3 was almost eliminated and only Area 1 continued to have significant amounts of infiltrated precipitation due to the section conserved as a Permanent Preservation Area (Figure 7 and Figure 8).

4.2. Reduction in infiltration and increase in surface runoff – effects on erosive processes at the Gated Community Alto da Boa Vista

Figure 9 presents a timeline containing the sequence of events up until the consolidation of the community's urban conversion.

The data indicate that there was a significant reduction in infiltration during the first years of soil conversion in Areas 1, 2, and 3 and, consequently, an increase in surface runoff. Surface runoff is a natural process that, although generally associated with negative impacts, only reflects careless changes in the surface coverage of rural or urban river basins (Santos, 2022).

The project removed vegetation cover, allowing soil to be exposed. The exposure of bare

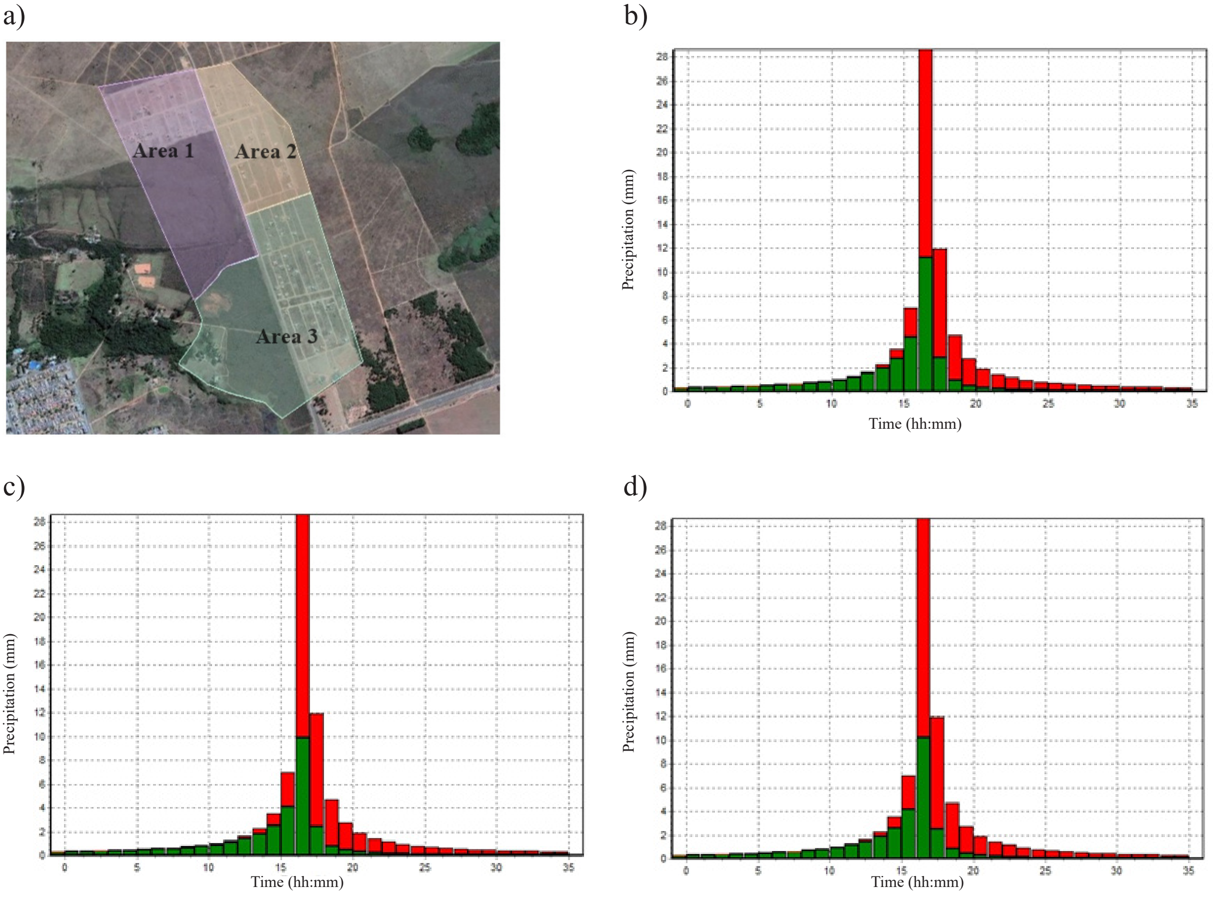

FIGURE 5 - (a) Effects of subdivision and precipitation in the three areas of the Gated Community Alto da Boa Vista (2009). Surplus rainfall hyetograms for 2009 in Area 1 (b), Area 2 (c), and Area 3 (d), with infiltration values in green and runoff values in red.

SOURCE: Produced by the Authors, based on *Google Earth* (2023).

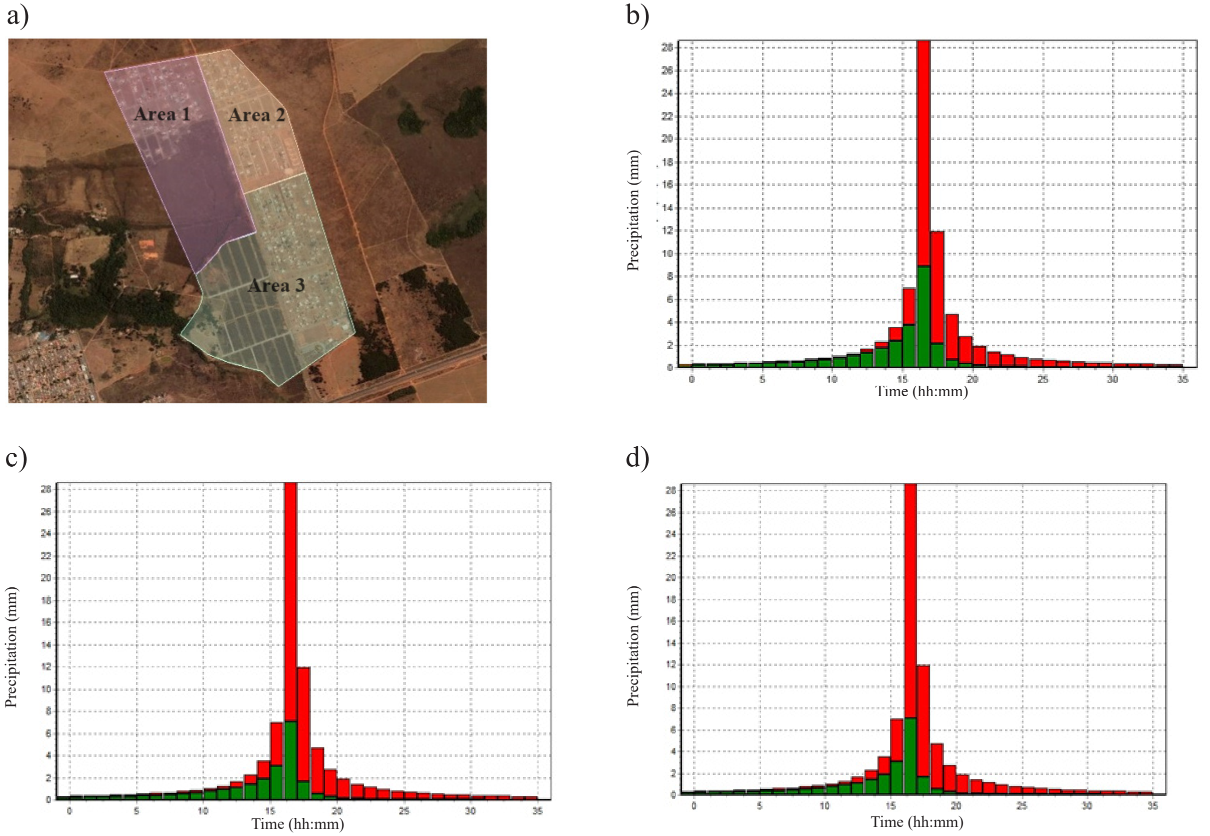

FIGURE 6 - (a) Effects of subdivision and precipitation in the three areas of the Gated Community Alto da Boa Vista (2015). Surplus rainfall hyetograms for the year 2015 for Area 1 (b), Area 2 (c), and Area 3 (d) with infiltration values in green and runoff values in red.
SOURCE: Produced by the Authors, based on *Google Earth* (2023).

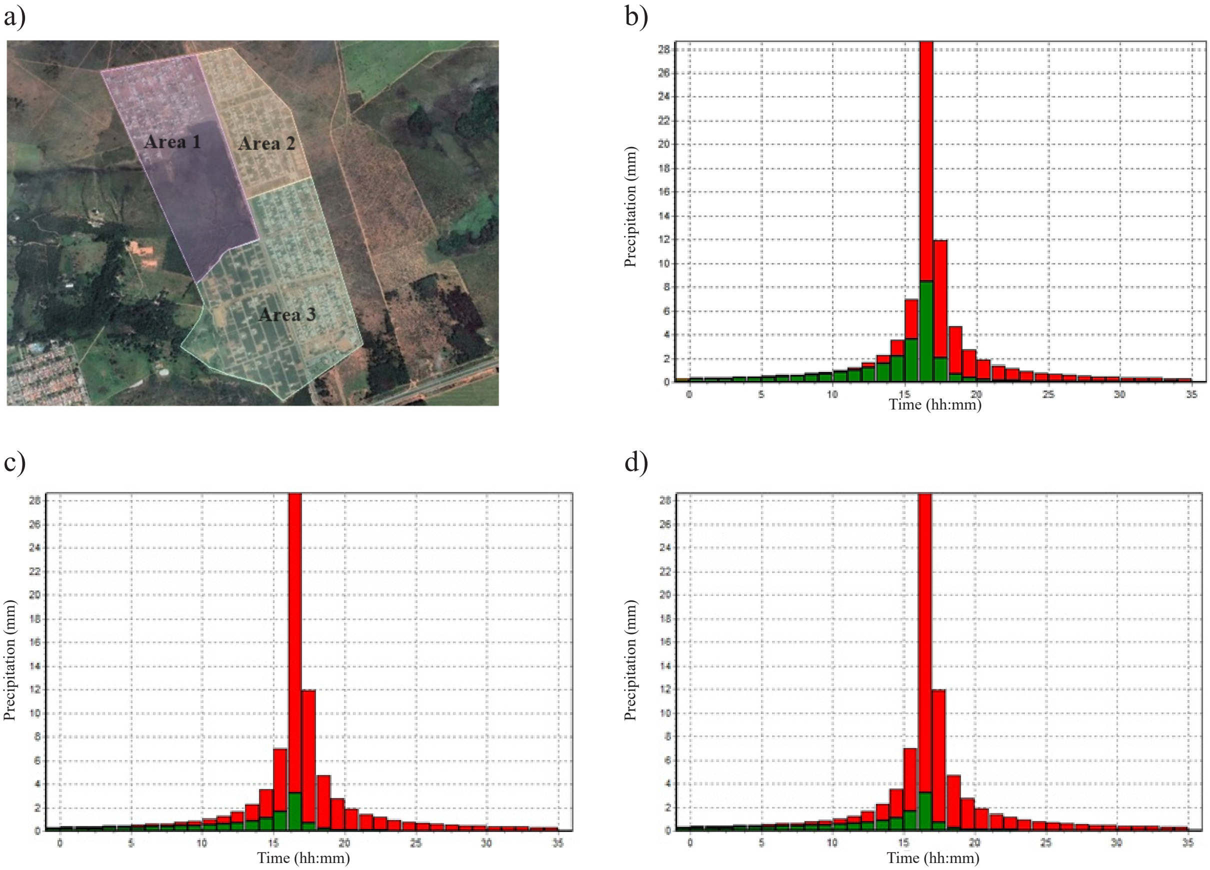

FIGURE 7 - (a) Effects of subdivision and precipitation in the three areas of Gated Community Alto da Boa Vista (2017). Surplus rainfall hyetograms for the year 2017 for Area 1 (b), Area 2 (c), and Area 3 (d) with infiltration values in green and runoff in red.

SOURCE: Produced by the Authors, based on *Google Earth* (2023).

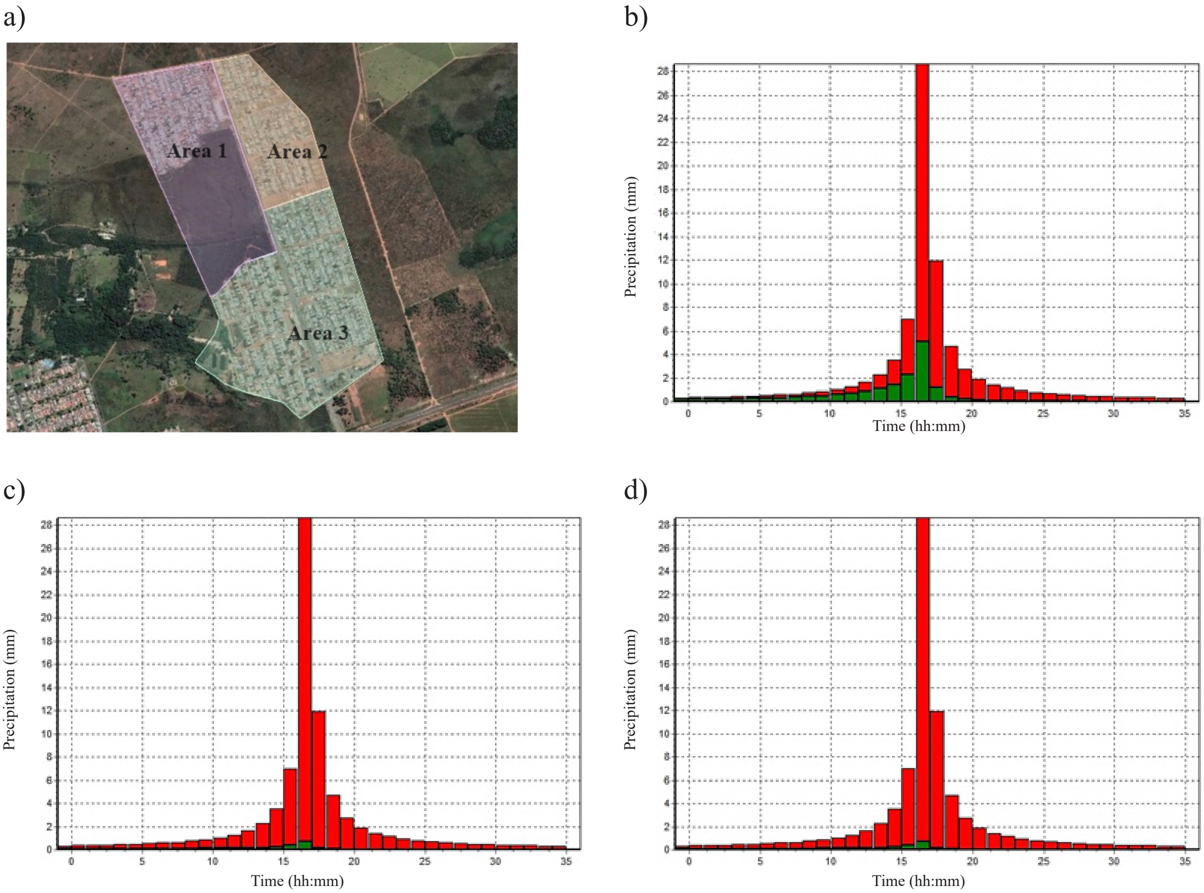

FIGURE 8 - (a) Effects of subdivision and precipitation in the three areas of the Gated Community Alto da Boa Vista (2012). Surplus rainfall hyetograms for the year 2012 for Area 1 (b), Area 2 (c), and Area 3 (d) with infiltration values in green and runoff values in red.

SOURCE: Produced by the Authors, based on Google Earth (2023).

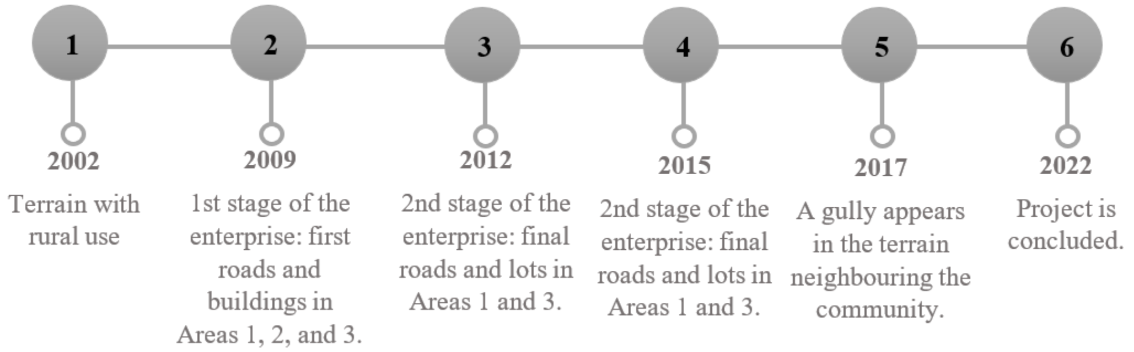

FIGURE 9 - Timeline of the process of soil use conversion and the emergence of erosive phenomenon at Gated Community Alto da Boa Vista (2002-2022).
SOURCE: Produced by the Authors.

earth to precipitation caused surface runoff to gain the potential of generating negative impacts, such as erosion and silting.

Concomitantly with the completion of land conversion in Areas 1 and 3 between 2015 and 2017, we recorded the formation of a gully outside the project, close to its southwestern border. Its beginning is visible when comparing images from 2014 and 2015 (Figure 10 and Figure 11). In Figure 10, vegetation is still dense, and there is no evidence of exposed soil in the humid area; however, in Figure 11, we see portions of exposed soil and reduced vegetation density.

Coinciding with the drastic reduction in infiltration in Area 3 (Figure 3), also present to a lesser extent in Areas 1 and 2, erosive features located on the limits of the community worsen and the area turns into a gully in 2017 (Figure 12). Until the appearance of the gully, the land undergoing erosion received contributions not only from Area 3 but from the entire area, since the project had not yet completed the drainage and rainwater management systems. Surface runoff went through the streets that converged on the community's central road, which functioned as a large rainwater drainage channel.

Analyzing the area more closely allows us to identify the behavior of the water flow on the ground that converges towards the erosive phenomenon (Figure 13).

The images demonstrate that the conversion of the rural area into an urban area altered soil cover and changed the flow dynamics, worsening the course of the natural erosion process.

5. Discussion

5.1. Process of urban and environmental regularization of the Gated Community Alto da Boa Vista

Although the conversion of the rural area into a gated community began in 2005, the developer initiated its process of regularization as an urban area in 1992. Environmental licensing for the community began in 1998, at the Federal District's Secretariat

FIGURE 10 - The area recorded in the red rectangle in 2004 does not show a gully, which appears in 2015.
SOURCE: Produced by the Authors, based on *Google Earth* (2022).

FIGURE 11 - In the red rectangle, the area recorded in 2015 shows the beginning of the erosive process.
SOURCE: Produced by the Authors, based on *Google Earth* (2022).

FIGURE 12 - In the red rectangle, the area affected by a gully in 2017.
SOURCE: Produced by the Authors, based on *Google Earth* image (2022) and on aerial survey by VANT.

FIGURE 13 - Area reached by gully in 2020.
SOURCE: Produced by the Authors, based on Google Earth image (2022) and on aerial survey by VANT.

of the Environment, with a request of a preliminary license. Such licensing was followed the rules of Resolution #237 issued by the National Council of Environment – CONAMA, on December 19th, 1997 (Distrito Federal, 2022). In 2000, the Secretariat issued the preliminary license – Preliminary License #022/00 – SEMARH (Distrito Federal, 2022). This license required that a full environmental impact study be made, together with its respective environmental impact report (EIA-RIMA).

Installation of the project was authorized only 17 years later, by Installation License (LI) # 003/2017– Instituto Brasília Ambiental (IBRAM) (Distrito Federal, 2017). Urban regularization of the area occurred in November of 2011, through the registry "Descriptive Memorial of Subdivision Regularization: MDE-RP – 051/99" (Distrito Federal, 2011), almost two decades after the application for the first urban regularization. Thus, it took the developer 25 years to complete the regularization of the project – which included the environmental installation license and the registered MDE-RP (Distrito Federal, 2011).

The developer followed the required procedure to offer the regularized plots that would form the gated community. He requested *a priori* urban and environmental licenses and provided all the necessary blueprints and studies. However, instead of waiting a reasonable amount of time for the outcome of his process (from the initial petition until the full description of the project was registered at a notary's office), in 2004 the developer began to install street infrastructure. Technically, the project began as a clandestine subdivision, not approved by public authorities. Over time, it became an irregular subdivision, i. e., a subdivision that was approved by public authorities but was not executed in accordance with its administrative act of approval (Saule Júnior, 2008).

5.2. The connection between environmental and urban irregularities and environmental damage resulting from land subdivision

According to Melo (2011), the irregular status of a subdivision can occur in at least two ways. First, when the developer or subdivision owner obtains municipal urban approval but does not submit the rest of the documentation required for registration by the competent real estate office. In this case, the complex approval procedure involving urban, environmental, and registration phases is interrupted or delayed for some reason, leading the developer to believe there is not a realistic deadline for its completion. The second manner by which a subdivision becomes irregular occurs when, after the initial phases required to start selling individual lots, the project is not carried out in accordance with the original plan (public road layout, institutional areas, green areas, size of the plots etc.). Alternatively, an irregular status may emerge if the developer does not comply with the predicted schedule for construction of the subdivision's infrastructure.

In the case under study, the developer illegally started installing streets and plots before registering the subdivision with a notary. However, the public sector also failed by granting provisional notary registration to the project before the environmental installation license was issued - the license would guarantee, in principle, compliance with measures to mitigate environmental damage.

In this context, the sluggishness of public administration is a factor that impacts the natural environment, the supply of regularized real estate, and the price of real estate. All of this directs the consumer to the informal housing market. As described by Da Mata et al. (2009), protracted environmental licensing, delayed approval and registration procedures for new subdivisions, and backlogs in the regularization of existing subdivisions negatively impact the expected financial returns of developers and real estate companies. Regulatory and legal uncertainties cause uncertainty and entail costs to immobilized capital.

On the other hand, public authorities still do not consider waterproofing a factor in environmental degradation and do not use available information to deal with the impacts of urbanization on water resources. In this context, it is crucial to manage natural resources and rural areas in a way that directs planning and/or regulatory approaches to reduce the combined area of impermeable land (Arnold & Gibbons, 1996).

However, the major victim of clandestine and irregular urban subdivisions is the natural environment. As demonstrated in the case of Gated Community Alto da Boa Vista, the installation of infrastructure without due intervention from public authorities caused erosive processes that could have been avoided based on compliance with technically suggested requirements in the urbanization project, especially those relating to drainage and rainwater management.

Despite the irregularities in the case of this gated community, the subdivision was created according to the proper procedures of urban regularization. Public authorities played their role by following the protocols of urban planning and environmental licensing. However, the amount of time spent in issuing licenses and the nature of the requirements were not consistent with the goal of preventing environmental damage.

An important gap in the regularization process is the lack of standards for developing urban drainage systems for different environments and hydrological cycles. These standards could give systematic support for technical requirements. Reis *et al.* (2020) found that, within the standards defined by the Brazilian Association of Technical Standards (ABNT), regulations closest to the topic of urban drainage systems refer to the drainage of agricultural areas (standards NBR 14.143/1998, 14.144/1998 and 14.145/1998), rainwater installations in buildings (NBR 10,844/1989), and procedures for building trenches for water, sewage or urban drainage pipes (NBR 12,266/1992). Standards to prepare and implement urban drainage projects are lacking.

In this context, the urban project approved for the Gated Community Alto da Boa Vista dealt only with isolated aspects of rainwater management. The project required a minimum permeability rate of 40% of units for residential lots and 30% in the unbuilt areas reserved for multiple-use lots. However, the same urban planning project also tolerates the installation of waterproof floor interspersed with permeable surface in a percentage of 15% of the area of single-family plots and 10% for multiple-use plots, reducing the permeable area in the plots. Another bogus action requires the MDE-RP – 051/99 to determine an aquifer recharge box in the part of the project where the water table is less than 7 meters deep (Distrito Federal, 2011). However, since technical criteria for soil permeability were not part of the requirements, actions were not designed for integrated rainwater management.

The only reference in the MDE-RP - 051/99 aimed at a broader system of rainwater management is one that determines that developers present the general design plan for rainwater drainage, indicating discharge points and the most suitable alternatives for a viable drainage system. However, at no time does the registered MDE-PR determine the adoption of technical drainage systems appropriate to the physical characteristics of the area. Likewise, it does not require the community's urban design to be compatible with its physical environment. The result in the studied community is that the main avenue runs perpendicular to the contour lines, which turns it into a large rainwater drainage channel.

The community under study adopted the predominant form of traditional urban drainage systems based on outdated precepts, as Christofidis (2010) describes. These precepts result in systems that allow rapid rainfall drainage discharges the collected effluents into bodies of water. These precepts cause strong impacts on the environment, making the systems unsustainable in the long term, considering the city's expansion.

Like MDE-RP - 051/99, Installation Licence nº 003/2017 - IBRAM did not indicate structural measures to prevent environmental damage caused by land conversion. The only required action is isolated: condition 15 determines that all local and secondary roads must be paved with permeable materials, observing applicable ABNT technical standards (Distrito Federal, 2017).

Once again, demands made by public authorities were limited to the application of an isolated requirement, ignoring other components of rainwater systems. This led the developer to formulate, in 2013, a rainwater system that included only traditional drainage measures. Given the environmental damage caused to the basin, the developer redesigned the project in 2019, focusing on the reduction of peak flows by means of rainwater retention basins. Although retention basins reduce runoff speed at discharge points, they are macro drainage mechanisms adopted in large scale in traditional drainage systems. These systems do not allow water to infiltrate the soil, which is necessary to recharge aquifers and minimize erosion processes resulting from surface runoff.

It is important to add that recharging river basins is a fundamental requirement of water security in cities, as they become increasingly impermeable and subject to flooding, inundations, and pondings. Therefore, public authorities need to include specifications in their urban regularization procedures which induce developers in the real estate sector to plan and adopt "sustainable urban drainage systems" (SUDS) (Woods-Ballard et al., 2007).

Our analysis of the case of the Gated Community Alto da Boa Vista identified three facts that contributed to make a potentially degrading urban subdivision project into an actually degrading project:

(i) sluggishness of public administration in granting urban and environmental licenses, out of step with the dynamics of the real estate market and the sector's investment deadlines;

(ii) granting property registration to subdivisions allowing plot sales without the prior establishment of infrastructural conditions that would mitigate resulting environmental damage; and

(iii) public authorities' requirements of random measures without technical criteria that would ensure their effectiveness in preventing environmental damage, such as that caused by rainy events.

Therefore, to avoid erosive phenomena such as those generated by the Gated Community Alto da Boa Vista, it is necessary for public authorities to act efficiently to impose the installation of sustainable rainwater management systems. These systems must contain the following elements:

(i) urban design compatible with the physical characteristics of the land;

(ii) rainwater control mechanisms at the source by installing equipment such as permeable pavements, ditches, infiltrations areas and trenches, grassy strips, and green roofs; and

(iii) rainwater management drainage systems that can capture non-infiltrated surplus water.

6. Final remarks

Urban subdivision regularization combines normative instruments related to different sectors: dominance, urban, and environmental. These instruments are complex and to achieve registration and regularization of properties they must be analyzed by professionals with different backgrounds. Despite this, it is not acceptable that this should take decades to be completed. Sluggishness of this magnitude encourages companies and people to chose illegal real estate ventures.

These delays also lead to major social and environmental losses, worsened when combined with the lack of technically adequate and integrated requirements to install drainage systems and rainwater management. City management is not apart from water management. Consequently, urban planning must consider water as a central component to be reckoned with. Cities, once they are built, change hydrological cycles but continue to be part of them. Therefore, it is impossible to ignore their effects on the urban environments and the effects of the urban environments on hydrological cycles. Rainwater drainage cannot be a marginal component of infrastructure projects in new urban areas or urban areas undergoing regularization.

Land regularization of the Gated Community Alto da Boa Vista is a clear example of how urban expansion, even if approved and licensed, can proceed without adopting the best techniques and causing significant environmental damage. The subdivision's history shows that:

(i) the public sector needs to demand urbanization projects from developers which minimize environmental damage as much as possible; and

(ii) developers must have the right to follow the administrative steps for approving urban subdivisions within reasonable time frames.

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