EVALUATION OF THE EFFECTS OF URBAN DENSIFICATION ON HYDROLOGICAL DYNAMICS OF WATERSHED - APARECIDA DE GOIÂNIA – GO

AVALIAÇÃO DOS EFEITOS DO ADENSAMENTO URBANO NA DINÂMICA HIDROLÓGICA DE BACIAS HIDROGRÁFICAS – APARECIDA DE GOIÂNIA – GO

EVALUATION DES EFFETS DE L'ADHESION URBAINE SUR LA DYNAMIQUE HYDROLOGIQUE DES BASSINS HYDROGRAPHIQUES - APARECIDA DE GOIÂNIA – GO

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Abstract

The expansion and urban densification in the last four decades have influenced the hydrological dynamics of urban watershed. The goal of this paper is to evaluate the intensification of this process, considering the changes in the coefficients of runoff in the face of precipitation scenarios, and its influence in the increase of the flow estimates of a watershed in Aparecida de Goiânia. The methodology consisted in the modeling of geoprocessing conditioners, involving precipitation, morphometric variables, coverage and use classes associated with soil types, and their effects on flow estimates in 1992, 2005 and 2016. The results indicate a close spatial-temporal correlation between urban densification and flow estimates, and in the basin exudative the maximum estimated flow increased from 16.2 in 1992 to about 46.8 m³/s in 2016. In the same period and in the whole basin the reduction of the concentration time was only 5.3 minutes in contrast to the considerable increase in the estimates of the flow velocity of the densely built areas. It is understood that the channels, herewith of the floodplain, functioned as reducing areas of the flow velocity enhanced by the increase and convergence of flow volumes from the higher areas.
Keywords: Soil sealing, runoff, estimates flows.

Resumo

A expansão e o adensamento urbano nas últimas quatro décadas influenciaram na dinâmica hidrológica de bacias hidrográficas urbanas. O objetivo deste trabalho é avaliar a intensificação desse processo, tendo como base mudanças nos coeficientes de escoamento superficial em face de cenários de precipitação, e sua influência no aumento das estimativas de vazão de uma bacia hidrográfica em Aparecida de Goiânia. A metodologia consistiu na modelagem dos condicionantes por geoprocessamento, envolvendo precipitação, variáveis morfométricas, classes de cobertura e uso associadas aos tipos de solo, e seus efeitos nas estimativas de vazão em 1992, 2005 e 2016. Os resultados indicam uma estreita correlação espaço-temporal entre o adensamento urbano e as estimativas de vazão, sendo que, no exutório da bacia, a vazão máxima estimada passou de 16,2 em 1992 para cerca de 46,8 m³/s em 2016. No mesmo período e em toda a bacia, a redução do tempo de concentração foi de apenas 5,3 minutos, em contraste com o considerável aumento das estimativas de velocidade de escoamento das áreas densamente edificadas. Entende-se que os canais,

juntamente com a planície de inundação, funcionaram como áreas redutoras da velocidade de escoamento, intensificadas pelo aumento e pela convergência de volumes de fluxo advindos das áreas mais elevadas.
Palavras-chave: Impermeabilização do solo, escoamento superficial, estimativas de vazão.

Résumé

L'expansion et la densité urbaine au cours des quatre dernières décennies ont influencé la dynamique hydrologique des zones fortement urbanisées. L'objectif de ce travail est d'évaluer l'intensification de ce processus, basée sur les changements dans les coefficients de ruissellement face aux scénarios de précipitations, et son influence sur l'augmentation des estimations de débit d'un bassin hydrographique à Aparecida de Goiânia. La méthodologie consistait à modéliser les conditionneurs de géotraitement, en incluant les précipitations, les variables morphométriques, les classes de couverture et d'utilisation associées aux types de sols et leurs effets sur les estimations de débit en 1992, 2005 et 2016. Les résultats indiquent une corrélation spatio-temporelle étroite entre les densités urbaines et les estimations de débit: dans le débit sortant du bassin, le débit maximal estimé est de 16,2 en 1992 à 46,8 m^3/s en 2016. Dans la même période et dans tout le bassin, la réduction du temps de concentration n'était que de 5,3 minutes contrairement à l'augmentation considérable des estimations de la vitesse d'écoulement des zones densément construites. Il est entendu que les canaux, avec la plaine d'inondation, ont fonctionné comme des zones réductrices de la vitesse d'écoulement renforcé par l'augmentation et la convergence des volumes d'écoulement des zones supérieures.
Mots-clés: L'imperméabilisation du sol, ruissellement de surface, Les estimations de débit.

Introduction

In the last four decades some of the urban environments are experiencing strong changes in the cover and use as a consequence of the expansion and concentration of buildings. This process has as key in properties, such as permeability and porosity, and not the behavior of the soils, due to the occurrence of rainfall, with the name of, mainly, in the hydrological dynamics of the watershed (Thielen et al., Hammond et al., 2013). In the context, it is worth noting the compaction and waterproofing processes that imply a marked reduction of the soil infiltration capacity, resulting in an increase in the ratio between the volume drained and intensity of 50 mm/h, there may be critical situations, in which the velocity increase is a convergence of large flow volumes, resulting in peak flows (Porto, 1995; Garotti; Barbassa, 2010; O'Driscoll et al., 2010).

In the Metropolitan Region of Goiânia, the greater appreciation of the territories has already been more densely occupied and most of the great circulation routes have been influenced by the overuse of areas for the construction of houses. As a result, the plots became smaller and smaller, with larger built-up areas in densely built areas (Morell et al., 2012, IPEA, 2015, Correia et al., 2016 and Kneib, 2016). It also influenced the search for areas that are based on housing, and began to build inclusive housing in areas that, under current legislation, should be of permanent preservation. In such context, Aparecida de Goiânia stands for this process, for this city experienced the largest rates of urbanization in the last decades. (IBGE, 2011; Souza; Borges, 2015).

Thus, the general objective of this paper is to evaluate the intensification of the process of expansion and urban densification and its influence on the hydrological dynamics in Tamanduá stream watershed in the years of 1992, 2005 e 2016. For specific objectives, the paper proposes: a) to evaluate the changes in cover and use, with special attention paid to both processes of soil compaction and waterproofing, and the relation with surface runoff coefficients; b) to evaluate the influence of the enlargement of areas with high runoff coefficients towards speed and the consequent reduction in time for concentration of the surface runoff; and c) assess the cumulative effects of such factors in the increasing of flow rate estimates.

Materials and Methods

Location and characterization of the study area

The study area comprises the catchment area of the *Tamanduá* stream, which is on the right bank of the *Meia Ponte River*, in the municipality of *Aparecida de Goiânia*, the second with the highest demographic density in the Metropolitan Region of Goiânia (Aragão; Arrais, 2013). It comprises an area representative of the growing urbanization process that occurred in the last three decades, extending beyond the already densely urbanized and conurbated area to the southern portion of the state capital (Arrais; Pinto, 2008). Another aspect is that, in addition to the large area in-between river basins of flat relief, the process of urban densification now occurs in almost all the parts of the watershed, such as those of greater slope and near the drainage channels, as can be verified in Figure 1, and which has influenced the hydrological dynamics throughout the system.

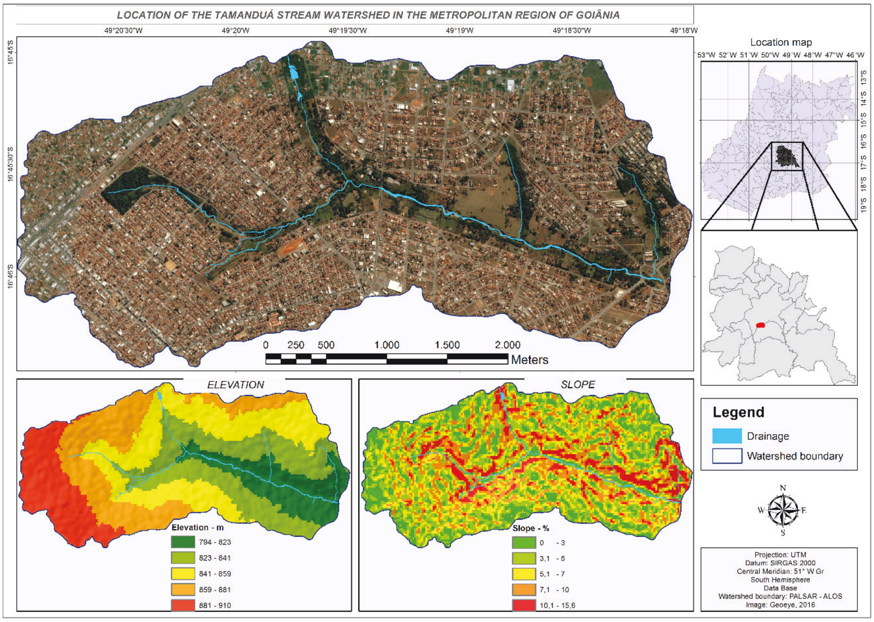

Figure 1 - Location of Tamanduá stream watershed in the Metropolitan Region of Goiânia

Source: Elaborated by the authors (2018).

Methodology adopted

The methodology consisted in the spatial-temporal correlation between changes in soil cover and use, as well as their correspondence in surface runoff coefficients, and the increase of flow estimates in the years 1992, 2005 and 2016. For the determination of the estimates of flow was applied the hydrological model Rational Method (Mulvaney, 1851; Kuichling, 1889), expressed by the following equation:

$$Qmax = CiA/3,6$$
(Equation 1)

Where: Qmax = estimated maximum runoff flow, in m^3/s; C = coefficient of surface runoff or ratio between the volume drained and the total precipitate, dimensionless; i = mean maximum precipitation intensities, in mm / h, with rainfall duration equal to or greater than the runoff concentration time; e A = watershed area in km^2.

To do so, the runoff coefficients were determined based on the proposal of the Soil Conservation Service (SCS) - US Department of Agriculture (1971), which was revised and applied by the Federal Highway Administration (FHA) - US Department of Transportation (2013), and was based initially on the effective precipitation, which results from the relationship between the precipitation considered and the water infiltration capacity in the soil, as shown in the following equation:

$$Pe = \frac{(P-0{,}2\ S)^2}{(P+0{,}8\ S)}$$

(Equation 2)

Where: Pe = effective precipitation converted to surface runoff, in mm; P = maximum precipitation considered, in mm; and S = storage coefficient, in mm. This results from the relationship between hydrological groups, which result from the assessment of soil characteristics, especially texture and depth, and the type of cover and use, resulting in CN values, according to the Natural Resources Conservation Service (NRCS) - USDA (1997), using the following equation:

$$S = \frac{25400}{CN} - 254$$

(Equation 3)

As observed in Equation 2, this relationship also considers an initial loss of about 20% of the volume precipitated as a result of interceptions and retention in depressions. However, the coefficients of flow resulted from the ratio between the volume of runoff and the total precipitation considered, as shown in the following equation:

$$C = \left[\frac{(P-0{,}2\ S)^2}{(P+0{,}8\ S)}\right] * 1/P$$

(Equation 4).

Where: C = surface runoff coefficient or ratio between the flow volume and the total precipitate, dimensionless.

Coverage and land use maps were elaborated through sequential and logical assessment from 1992 aerial photographs in gray levels (IPLAN, 1992), and images of the 2005 and 2016 Quickbird and Geoeye satellites, all with spatial resolution of 50 cm by means of supervised classification, maximum likelihood classifier and field validations for the areas that remained unchanged. However, for the elaboration of the models of slope and length of flow we used of the Digital Model of Elevation ALOS-PALSAR, corrected and with spatial resolution of 12,5 meters. The results, especially of the application of Equations 2, 3 and 4, using the CN values and considering a precipitation of 78.46 mm for the year 2016, can be checked in Table 1, which presents the main classes coverage and land use considered and mapped for each year evaluated.

Condição do Terreno	CN	S - mm	Precipit. Effective - mm	Coef. R.O. Sup.
Built Area	98	5,18	72,56	0,925
Paved Surface	97	7,86	69,76	0,889
Compacted Exposed Soil	76	80,21	27,32	0,348
Uncompacted Exposed Soil	68	119,53	17,10	0,218
Compacted Grassy	66	130,85	14,93	0,190
Uncompacted Grassy	61	162,39	10,15	0,129
Isolated Tree	62	155,68	11,03	0,141
Gallery Forest	29	621,86	3,66	0,047

Table 1 - Classes of use and occupation of the soil and respective coefficients of surface runoff.

Source: elaborated from the data of CN constants in Tucci and Marques (2001), through equations 2, 3 and 4.

The mean maximum precipitation intensities were estimated according to the relationship proposed by Vilela and Mattos (1975), which relates the intensity - duration - frequency (FDI) of the meteorological events, using the rainfall history systematized by Oliveira et al. (2005) for the region of Goiânia by means of the following equation:

$$Im = \frac{K \times Tr^{a}}{(t+b)^{c}} \Rightarrow Im = \frac{920,45 \times Tr^{0,1422}}{(t+12)^{0,7599}}$$

(Equation 5)

Where: Im = mean maximum precipitation intensities, in mm / h; K, a, b and c = own parameters of the climatological station; T = return time, in years for an extreme event; and t = time of concentration of the runoff that should be less than or equal to the time of rainfall duration in the basin area, in minutes. In the present work, a return time of 12 years, compatible with commercial areas and traffic arteries was considered (Porto et al., 2004). The time of rainfall duration resulted from the time of concentration of the runoff, of the whole basin, estimated for the years 1992, 2005 and 2016. These were determined by the Kinematic Method, according to the SCS-USDA (1971) by means of following equation:

$$Tc = 1/60x\Sigma \frac{Li}{Vi}$$

(Equation 6)

Where: Tc = time of concentration of the surface flow, in min; 1/60 transform factor from seconds to minutes; Li flow length in the segment considered, in m; and Vi = velocity of the runoff, in m/s.

The runoff velocity was estimated based on the evaluation of flow coefficients and slope, as proposed by Porto (1995), using the following equation:

$$Vi = Cv \times Si^{0,5}$$

(Equation 7)

Where: Vi = runoff velocity, in m / s; C = coefficient of surface flow, dimensionless; and Si = slope, in %, raised to the exponent 0.5.

Due to the fact that the basin has an area greater than 3 km^2, a delay coefficient was applied as a function of the area of the same, resulting in what is known as Modified Rational Method, as proposed by Pinto et al. (1976) and Euclydes (1987), whose formula is presented:

$$\theta = 0,278 - 0,00034\ S$$

(Equation 8)

Where: θ = lag coefficient as a function of the area of the basin; 0.278 and 0.00034 are constant and S = area of the basin in km^2. The basin area variable was used cumulatively, that is, transfer of the volume of cells upstream to downstream, resulting in the accumulation of surface flow as a function of the specific contribution area (Nunes, 2015). This artifice provided the application of all the equations and, consequently, of all the calculations for each of the 65,894 12.5 x 12.5 m cells of the MDE, belonging to the basin, which allowed the elaboration of a spatially distributed model with the greater value of flow estimation corresponding to the basin exudative. Otherwise, only one calculation would have been performed, with the resulting value being representative of the whole area of the basin without a representation of the spatial variability of the flow volumes. All the technical-operational procedures of this methodology were developed through the Math and Hydrology modules, available in the ArcGIS SIG (ESRI)[1].

Results and discussion

Changes in coverage and use and reduction of infiltration capacity in the watershed

Regarding changes in coverage and use and their implications for the reduction of soil infiltration capacity, it is worth noting that in 1992, despite the small percentage of constructed area, the classes of exposed non-compacted soil, compacted exposed soil and mainly grass, as shown in Figure 2, already occupied about 65% of the area of the watershed.

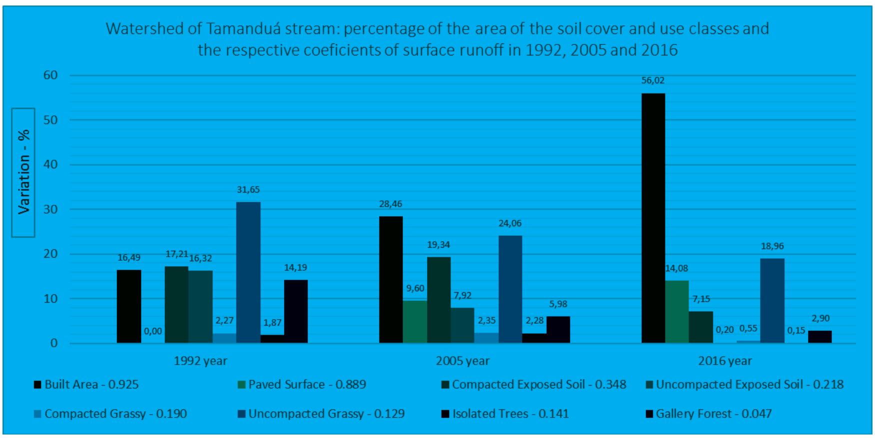

Figure 2 - Variation and relative area –% – of the classes of cover and land use, and respective coefficients of surface runoff between the years 1992, 2005 and 2016.

Source: Elaborated by the authors (2018).

For that year two aspects deserve attention. One refers to the high percentage of areas, such as grasses and exposed soil that in the following years were gradually converted into built-up area and paved streets, respectively. Another one refers to compacted exposed soil that in terrain with up to 11% of slope and coefficient of flow of 0,348 already limited the capacity of water retention and consequently altered the hydrological regime, increasing the speed of superficial flow along the streets.

The changes in coverage and use became more evident in 2005, when the soil compaction and waterproofing process was more pronounced due to the appearance of the paved surface which, together with the built up area and the compacted exposed soil, corresponded to about 57% of the entire basin. In this situation it is worth mentioning the class of built area which, besides corresponding to 28% of the total, has a high surface runoff coefficient, the resulting volume of which falls on the paved surface and then on the compacted exposed soil of unpaved streets. These areas, with high runoff coefficients and located in the higher portions, exerted more and more pressure on the few resurgent vegetation that, in that year, represented less than 6% of the total area and were located in the lower portions of the watershed.

By the year 2016, the watershed as a whole already showed signs of consolidation of the building process. Considering the whole area, about 56% was built and about 14% paved. In addition to the compacted exposed soil area in that year, about 77% of the basin had surface runoff coefficients ranging from 0.348 to 0.925. The areas still considered with some infiltration potential, such as gallery forest, occurred in less than 3% of the basin. The remaining 19% of the uncompacted grass class corresponded to the few land not yet built and located in the vicinity of the drainage channels. Part of this state of degradation was pointed out by Santana (2011), when he pointed out that, of the 9 sources, only two were in a state of preservation, and Carneiro and Barreira (2015), who emphasized the increase of anthropic pressure in the form of removal of vegetation, occupation of Permanent Preservation Areas, compaction of soils and occurrence of floods. In recent work Moreira Junior et al. (2016) highlighted the absence of vegetation cover and high stage of degradation of the margins with the occurrence of large border erosions reaching to compromise streets and residences. Similar processes and trends were found by Matos et al. (2011), when they analyzed the changes in the coverage and use in the Tucunduba Basin in Belém - PA. On the occasion, it was verified that the soils with high infiltration potential were the ones that had the most relative reduction in the infiltration capacity due to the advance of urbanization and urban densification.

Soil compaction and waterproofing and changes in hydrological dynamics

With reference to the applied hydrological model, focusing mainly on the intensity and duration relationship of the precipitation events in relation to the terrain conditions, it is possible to perceive the effects of the large-scale reduction of the soil infiltration capacity in the estimates of increase of the volume of flow superficial. In order to do so, the collections of elaborated maps represent, in a systematized way, the conditions of land cover and use and their correspondence in surface runoff coefficients, which in light of the intensity and duration of the pluviometric event result in flow estimates.

Considering the above, for the year 1992 the built area predominated in the higher portions of the watershed, especially along the main roads, such as state highways and main avenues surrounded by exposed soil areas. Thus, there is a gradation of runoff coefficients varying from 0.925 in built-up land and slopes of up to 11% to 0.218 in poorly constructed areas and streets under exposed soil conditions (parts **a** and **b** of Figure 3). Under these conditions, the runoff velocity varied from 1.51 for high coefficient and low slope surfaces to 3.52 m/s for surfaces with equally high and sloped coefficients. In lower slopes higher velocity flows were intercepted by areas with lower coefficient grasses, which allowed speeds to be reduced to less than 0.5 m/s near the main channels (part **c**). In these coefficient and flow rate conditions, and considering a precipitation intensity of 73.89 mm/h for a period of 31 min (part **e**), a maximum flow estimate of 16.2 m^3/s at the point of maximum convergence considered, as shown in part f of the same figure. Based on the same figure it is possible to notice that the flow length and runoff concentration time maps are very similar in terms of spatial distribution. This similarity is due to the division of the values of flow length by the velocities found in the basin. However, due to the generalized increase of the flow velocity in the area of the basin, for the next years the trend will be the reduction of the time of concentration of the surface flow, which in terms of spatial representation will imply in the upstream retraction of the greater and consequent greater comprehensiveness of the smallest classes of concentration time.

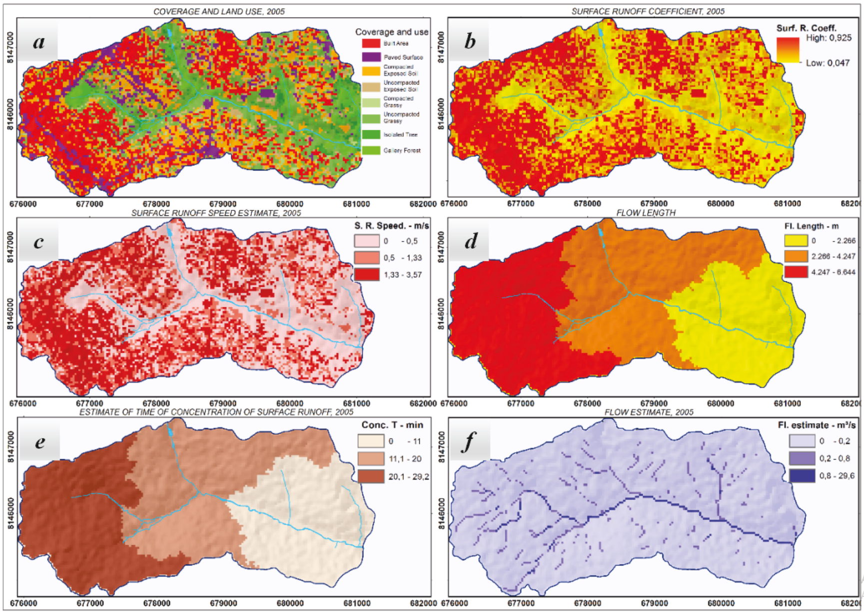

Figure 3 - coverage and use maps (*a*); of flow coefficients (*b*); of flow velocity (*c*); of flow length (*d*); of concentration time (*e*); and of flow estimate (*f*) of 1992.

Source: Elaborated by the authors (2018).

For 2005, in addition to the expansion of built-up areas to the medium-sized slopes, the paved area corresponding to the state highways, Belt way, main streets and avenues, as well as the courtyard of large buildings in the immediate vicinity. The class of exposed compacted soil presented a slight increase in relation to the year 1992 due to the fact that, in addition to occurring in the middle of the built area, it also extended to other environments, which previously were occupied by uncompacted exposed soil and mainly grasses, resulting in flow coefficients above 0,348 in more than 57% of the basin, as shown in parts a and b of Figure 4. The runoff velocities above 1.33 m/s, which in 1992 were restricted to the higher portions, in 2005 also came to predominate in the medium-sized areas and with estimates up to 3.57 m/s (part c of the same figure).

In this situation, two aspects deserve to be highlighted. One refers to the incidence of flows with high runoff velocity in exposed soil areas, significantly elevating the risk of erosive processes along streets and avenues. The other refers to the increase of areas with high surface runoff coefficients, whose effects converge to areas of diminishing vegetation remnants, which implies in the spatio-temporal configuration of anthropic pressure increase. This intensification can be verified from the joint observation of the parts c and e of Figure 4, in which the velocity increase and the reduction of the time of concentration of the surface flow in relation to the year of 1992 can be perceived in a general way.

Regarding the time of concentration, it is highlighted that in 1992 it took about 31 minutes for the entire area of the watershed to contribute at the most downstream point considered, whereas in the year 2005 this period became 29, 2 minutes. Considering the division of the time of concentration in classes, it is highlighted that in 2005 there was an increase in the areas covered by the classes from 0 to 11 and from 11.1 to 20 minutes, while the area of the class greater than 20 minutes suffered reduction. In practice, the lower class span of 20 to 29.2 minutes means less time required for the entire basin to contribute to the flow in the exudate. Under these conditions, and considering the runoff coefficients under a precipitation intensity of 75.63 mm/h during a period of 29.2 minutes, the estimation was of a maximum flow of 29,6 m^3/s at the point of maximum convergence considered, as shown in part f of Figure 4. Compared with the 1992 estimates, it is possible to verify that there was a reduction of the area with an estimate varying from 0 to 0.2 m^3/s and a significant increase of the area with an estimate varying from 0, 2 at 0.8 m^3/s.

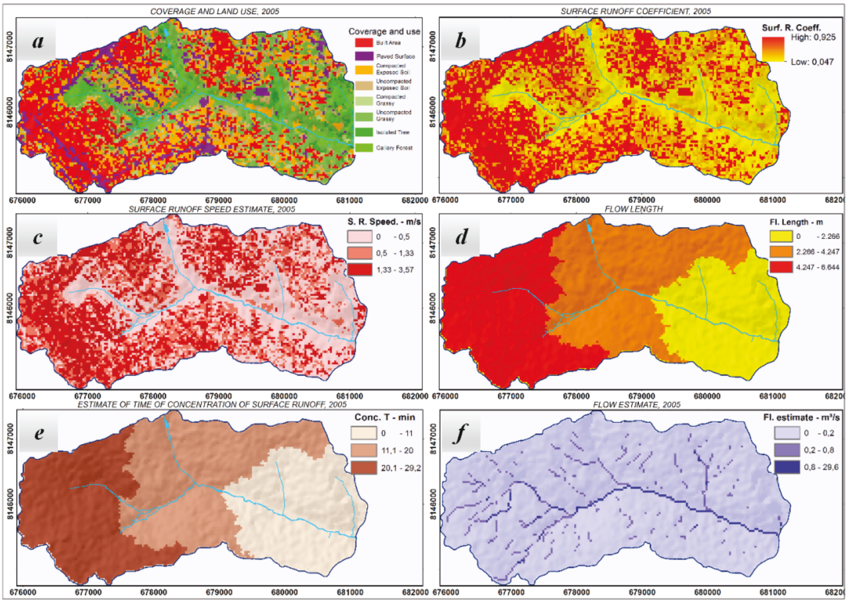

Figure 4 - coverage and use maps (*a*); of flow coefficients (*b*); of flow velocity (*c*); of flow length (*d*); of concentration time (*e*); and of flow estimation (*f*) of 2005.

Source: Elaborated by the authors (2018).

By 2016 there was a significant increase in compacted and mainly waterproofed areas in almost all sectors of the watershed, while the areas of uncompacted grasses and gallery forest remained in few segments in the vicinity of the main channels. In this situation, the areas with coefficients of surface runoff higher than 0.89 already prevailed in about 70% of the area and those equal to 0,348 in 7%, ranging from the high to the low and final segments of the slopes. In this context, a major difference compared to 2005 is in the built area, which doubled in terms of coverage, taking up about 56% of the basin. It is also worth mentioning the near disappearance of the class of exposed non-compacted soil, which from 7% in 2005, went to 0.2% in 2016, as shown in part **a** of Figure 5. This reduction is due to the advance and densification of urbanization which in 2005 prevailed in the higher and intermediate parts of rarefied form, whereas in 2016 it began to occupy almost evenly the entire area of the watershed, leaving about 70% of it with surface flow coefficients above 0.89 (part **b** of the same figure). The effect of these changes in flow velocity can be seen in part c of Figure 5, where it is possible to perceive the predominance of velocities above 1.33 m/s in almost all of the basin, especially in the higher and middle portions. Up to 3.82 m/s, in segments with high coefficients associated with slopes of up to 11%.

The predominance of high flow velocities from the higher portions to the intermediate segments suggests that the reduction of the time of concentration of the runoff in the higher segments of the slopes has been much larger than the reduction observed in the basin as a whole, along of the period considered. This is because in terms of flow length, the channels are up to 9 times larger than the slopes and the changes in coverage and use along the fluvial plain were less intense than those found in the higher parts of the slopes in the last 24 years. Thus, although it is observed an increase in the area of the classes from 0 to 11, from 11.1 to 20 and consequent reduction of the class from 20.1 to 25.7 minutes of the concentration time, it is understood that, considering the basin as the drainage channel with its sinuosity, together with the smaller changes in the coverage and use along the plain, contributed to a reduction of only 5.3 minutes in the time of concentration of the surface runoff in the analyzed period.

In the conditions of 2006, with the predominance of high runoff coefficients in most of the basin and considering a precipitation intensity of 78.43 mm/h during a period of 25.7 minutes, the estimate was of a maximum flow of 46.8 m^3/s at the maximum convergence point considered, as shown in part f of Figure 5.

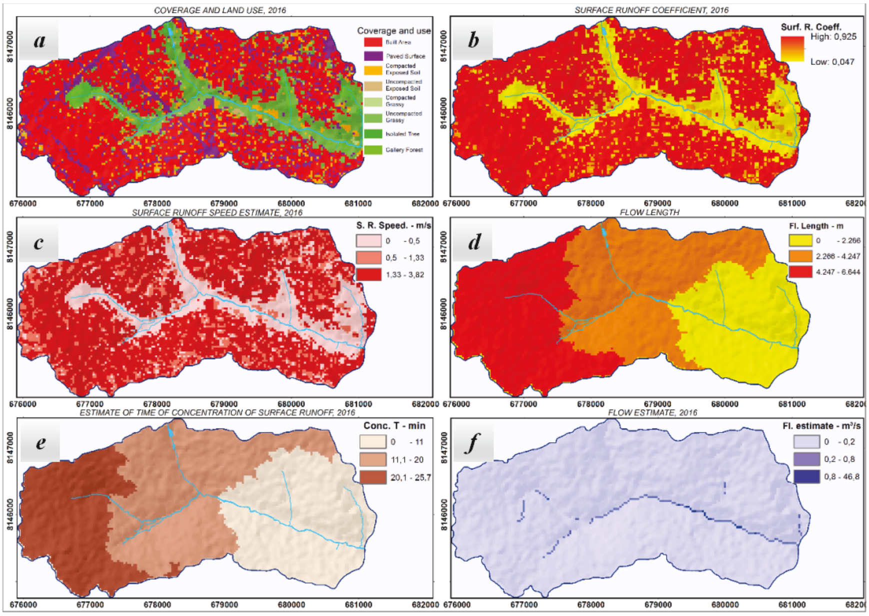

Figure 5 - coverage and use maps (*a*); of flow coefficients (*b*); of flow velocity (*c*); of flow length (*d*); of concentration time (*e*); and of flow estimation (*f*) of 2016.

Source: Elaborated by the authors (2018).

Final considerations

The work involving modeling by means of estimates aims to allow the representation of a given process or phenomenon of reality to assume a more cinematic, spatially continuous character and, consequently, increasingly fill the space-time gaps, in view of the static and punctual character of data measured directly in the field. However, as emphasized by Mitasova et al. (2006), models become more accurate and efficient as comparisons or confrontations are made between predicted scenarios and what actually occurs. From the above, it can be said that none of the ways of obtaining data overlaps, but that both complement each other. This is because the representation of processes and phenomena with high space-time variability, such as surface flow, from data collected directly in the field is extremely difficult, considering the need for a high amount of data, as well as the costs involved in monitoring of this nature. The models are born from this difficulty and, above all, from the need to predict scenarios for which there is no data, even in small numbers, thus allowing for predictions. That is why the models result from the systematized analysis of data and variables, as well as the observed trends, which give them a valuable way of evaluating the effects arising from the convergence of factors that allow more precise diagnoses and prognoses. As for the use of the CN method in surface runoff estimates, Soares et al. (2017) highlight good correlations achieved based on the comparison between the predicted values and the reality observed in several watershed.

In relation to the methodology and the results presented here, two aspects deserve to be highlighted. One refers to the fact that, given the heterogeneity of the types of use and cover, as well as of soils, we did not use the means, even if weighted, to establish the coefficients of surface runoff of the basin area. All cells of 0.5 x 0.5 m of each image were duly evaluated and classified for the most probable effects provided to the terrain when rainfall occurred. Another refers to the effect provided by the transfer of the surplus volume of upstream cells to those downstream, cumulatively, which resulted in a sequential and logical chain linkage as well as estimated flow volumes, as indeed occurs on the ground . This artifice proves to be of great importance, since it allows to evaluate qualitatively and quantitatively the cause-effect relation of a phenomenon in relation to its surroundings and conditioning variables.

With regard to the reduction of the runoff concentration time, it should be noted that, although in the period considered there was only a reduction of 5.3 minutes, it is important to note that this reduction may have been greater in the higher portions of the slopes, especially in segments of greater slope and that have undergone significant changes in coverage and use in the last 24 years. With this, the need for a complementary approach and involving only the areas of emphasis is highlighted. The main difference will be the calculation of the runoff velocity not involving the drainage channels, since the plain and especially the fluvial channel are areas that have undergone less changes in coverage and use. Such a strategy will allow the evaluation of changes in water flow behavior on the surface and on contact with drainage channels.

Another suggestion, which will allow a more comprehensive understanding of the effects of flooding in the hydrological dynamics of urban basins, refers to the assessment of the influence of anthropic pressure resulting in the balance of drainage channels as well as along the entire fluvial plain. This is because in hydrological terms all the pressure exerted in the form of increasing velocity as well as volume of flows tends to converge in the form of increase and concentration of kinetic energy for specific segments. Such concentration of energy will necessarily result in the accomplishment of work, which will take place in the form of edge erosions and consequent degradation of the fluvial plain. It is a way for these catchment areas to adapt to the new hydrological conditions.

The urban expansion and the densification of buildings along the surface of an open system, such as the hydrographic basin, necessarily imply the increase of surface water flows, which gradually converge in the form of lineaments and intensify, resulting in an increase in the flow volume. This is because, based on the coefficients of drainage of built-up areas - 0.925 - and areas with vegetation - 0.047 - it can be seen that the compaction and waterproofing process can reduce the water storage capacity in the soil by up to 88%. In dynamic situations, such as surface runoff, such low retention capacity generates cumulative effects as each plot of land ceases to absorb a specific volume of precipitated total and transfers it to downstream segments in order to make flows as the higher the velocity and the volume of flow.

Note

1 License: ESU993242249 / LABOGEF/IESA/UFG.

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Todos os autores prestaram substanciais contribuições científicas e intelectuais ao desenvolvimento do estudo. Os autores trabalharam em conjunto na concepção, estruturação e redação, bem como na revisão crítica. O autor Elizon Dias Nunes foi responsável pelo levantamento e estruturação do banco de dados geográficos, implementação das equações por meio de geoprocessamento e revisão textual. O autor Lana Lima Borba coube a tarefa de levantamento, avaliação e sistematização dos valores de coeficientes de escoamento superficial, avaliação e revisão das equações.