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Urban Flood Risk Reduction by Increasing Green Areas For Adaptation To Climate Change

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Abstract

Enhanced green infrastructure (GI) in urban areas, such as green roofs, parks and green spaces can make a significant contribution to enhancing the provision of fundamental ecosystem services (ES), through nature-based solutions. These positive effects include increasing the interception capacity due to increasing vegetation cover, increasing of storage capacity and infiltration of the soil, thus reducing storm water runoff, producing substantial improvements in the urban drainage system, whose infrastructure is very difficult and expensive to be modified. In this paper an indicator based on the runoff coefficient, which allows quantifying the impact on runoff due to increase of GI is presented. In a second step, a way for relating the indicator with the risk of flooding is proposed. The complete methodology was applied on an urban basin located in the north of Rosario city, Argentina. Four scenarios were evaluated: baseline scenario (current scenario), and three hypothetical (future) scenarios, considering a moderate and severe waterproofing situation respectively, and one green scenario with increased GI. The results show that the moderate and severe waterproofing scenarios produce an increased risk of flooding from 1.9 times to 4 times, respectively. This implies a necessary reinvestment in urban storm water infrastructure in order to keep the original security levels. The green scenario does keep the runoff coefficient, even considering the major increases in population and urbanization. Improving the GI constitutes a strong strategy to adapt to climate and urban changes, to cope with upcoming increases in precipitation and urbanization.
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1. Introduction

The sustained increase of land sealing in urban areas join to the increased annual rainfall due to the consequences of climate change global warming has become in a serious problem because both processes result in increased surface runoff. In east central part of Argentina, a significant increase in the frequency of extreme rainfall was recorded during the last decades. Flood damage, destructive winds and hail were associated with such events [5]. In a context of climate change, it is expected an increase of 1°C in the mean annual temperature and 13% in the mean annual precipitation, consequently increases in runoff, in the region for the period 2020-2040. With the increasing trends of urbanization, with cities in Latin America expanding at a pace of 20 m2/minute [3], this problem will become more complex and difficult to solve unless immediate measures developed in parallel with these processes are taken. It is urgent to define strategies to cope with this problem reducing the runoff by increasing the water intercepted captured by the soil and stored in different environmental containers. In terms of storm water, the positive effects of green infrastructures (GI) are mainly two: 1) increasing water interception due to vegetation cover, and; 2) increasing storage capacity and infiltration of the soil. The overall aim of this study was to assess the performance of GI land planning scenario on flood risk reduction in the city of Rosario, Argentina. An approach using conventional methods to evaluate the relative impacts of GI on flooding is proposed, specifically to be applied in cities lacking spatial data. The specific objective is therefore to determine a set of indicators describing the impacts in urban and peri-urban storm water runoff under different land use scenarios, and its relationship with flood risks for the study area.

2. Material and Method

2.1. Study area

The study is focused on the city of Rosario (Santa Fe province, Argentina), located at latitude 32° 57 S and longitude 60° 40' W (Fig. 1). Rosario has the most important port in South America for grain export (third place in the world in exports of soybeans). The climate is mild and humid, with average annual rainfall of the order to 1,000 mm and average annual temperature of 17°C. The current population of the city is about 1,000,000 inhabitants. The proposed methodology was applied on an urban basin located in the north -west of the city. The study area is on the old floodplain of Ludueña's stream, and has about 75,000 inhabitants. This watercourse crosses the north area of Rosario. This basin has an area of about 20 km^2 (1,952ha) with highly urbanized areas, low density suburban neighborhoods, industrial and rural areas (Table 1). In the last decades this area suffered a fast urban expansion mainly to provide housing at low cost of land, although was urbanized under exceptional rules.

Fig. 1. Location of Rosario in Santa Fe province, Argentina, google.com/maps/.

2.2. Indicator for evaluation the impacts on runoff.

The runoff coefficient of the rational method is used to determine a hydrological indicator that relates LULC changes and its impact on runoff. Rational method is often used to compute peak discharge from drainage basin runoff [2], and storm drains design. The indicator "reduction in runoff coefficient" ΔC [6] for the assessment of hydrological impacts at city-level between actual and future scenarios was proposed. Negative ΔC values for any time period will indicate a net decrease in runoff, which is reducing the risk of floods within that surface area. In a second step, changes of ΔC were related to changes in risks of flooding.

2.3. Relationship between reduction in run off coefficient and the risk of flooding

Using the rational method, the design discharge for an area without GI, at the time t (current scenario) and time t+1 (future scenario) are, respectively:

$$Q_t = C_t i_t .A \tag{1}$$

$$Q_{t+1} = C_{t+1} i_{t+1} .A \tag{2}$$

where Q is the design discharge, C is the runoff coefficient and i is the design rainfall intensity, all variables at time t or t+1. The rainfall intensity has a duration equivalent to the time of concentration (tc) of the watershed, at time t. In the situation at time t, the rainfall intensity, corresponds to a one level of protection determined (period time Tt). According with Kieffer y Chu (cited by [2]), the rainfall intensity can be presented as:

$$i = \frac{g.T^m}{d^e + f} \tag{3}$$

where T is the period time or recurrence, d is the duration and g, m, e, and f are constants that depend on local rain characteristics. Considering the risk of flooding reduction, since to increase of GI, the question is: what (probabilistic) new level of protection that would correspond to the design discharge Q_t (current drainage infrastructure) in the new situation at t+1 (C_{t+1})? Following these considerations, we can say that: $Q_t = C_{t+1}.i_{t+1}$. A where i_{t+1} is the rainfall intensity, associated with a period time T_{t+1} that in the new situation t+1 generate the discharge Q_t. Here we will assume, for simplicity, that the duration of the rain design does not change (tc does not change). Equaling equations (1) and (2) join to eq. (3), and simplifying we have:

$$\left(\frac{C_{t+1}}{C_t}\right)^{1/m} = \frac{T_t}{T_{t+1}} = \frac{P_{t+1}}{P_t} \tag{4}$$

where P_t and P_{t+1} are the exceedance probability of rainfall intensity at situations t and t+1, respectively [7]. Equation (4) represents the relationship between changes in runoff coefficients and respective changes in risk of flooding.

2.4. Scenarios.

Trends in Land Use/Land Cover (LULC) is a decisive factor determining the impact of the increased precipitation in the runoff and essential to be considered in developing planning scenarios. Firstly, a baseline scenario (Scenario 0) representing the current uses and land cover is proposed. LULC classes were defined by considering the characteristics of use, morphology and construction materials used, and then, runoff coefficients (C) have been assigned according (Fig. 2a). Secondly, based on the information of Scenario 0, three hypothetical LULC scenarios were proposed using estimated runoff coefficients: (1) a moderate scenario considering the current building "developable" area according to maximum levels permitted by urban regulations, (2) a severe scenario considering built the entire study area according to maximum levels permitted by urban regulations, and (3) a green scenario (considering GI) according to maximum levels of urbanization permitted by urban regulations. In scenarios 1 and 2 for the determination of the building densities current trends in land occupation were considered (Fig. 2b, 2c and 2d).

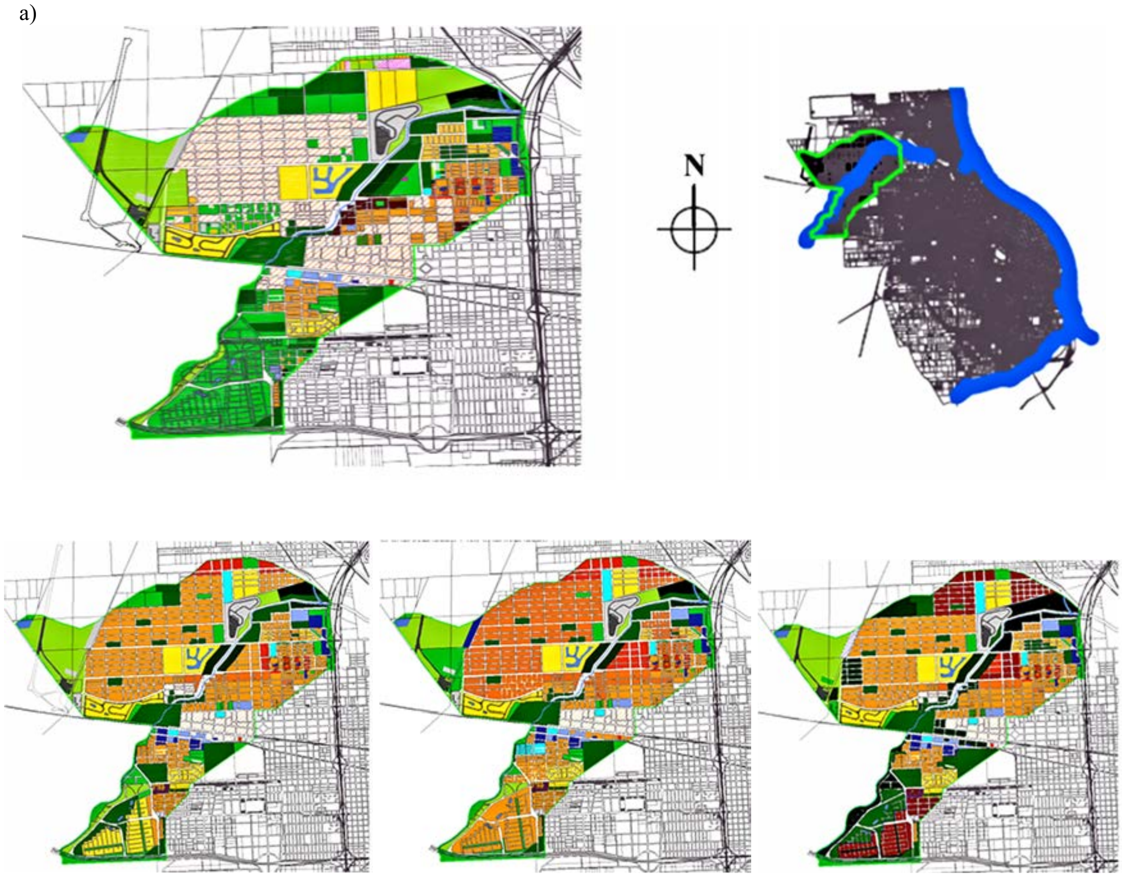
2.5. Calculation of indicators and flood risks for the proposed scenarios

Indicators were calculated considering the estimation of runoff coefficients for each hypothetical scenario with respect to the current scenario. For assessment of runoff coefficients, tables are provided by the literature. In this paper, tables proposed by [1] for urban areas and [4] for undevelopable areas, were used. Watershed runoff coefficients depend upon the land use, soil type and slope of the basin. All these variables were calculated and verified in situ.

3. Results and Discussions

Table 1 shows the difference between runoff coefficients for the proposed scenarios. With the current land use (scenario 0), the average runoff coefficient is 0.49 for all the study area. For the Scenario 1, the runoff coefficient reaches a value of 0.53, which implies an increase of about 8% of its current value. Considering the value of $m = 0.122$ adjusted for Rosario, applying equation (4) for a runoff coefficient increased 8% ($C_t+1/C_t=1.08$) which would cause an increased risk equivalent $P_t+1/P_t = 1.90$ times.

a)



b) c) d)

Fig. 2. Land use for Scenarios 0 (a); 1 (b); 2 (c); and 3 (d) in basin 3. Note: color codes are shown in Table 1.

Table 1. Runoff coefficients and percentage of occupation areas for different land use conditions and scenarios.

N°	Color code	Coverage	C	% Area for Scenario 0	% Area for Scenario 1	% Area for Scenario 2	% Area for Scenario 3
1		Pavement in public spaces	*0.90*	5.9	6.2	13.2	4.0
2		Single-family home, up to 2 floors (<occupation of land)	*0.60*	4.9	25.5	13.4	19.4
3		Single-family home, up to 2 floors (>occupation of land)	*0.65*	0.1	0.9	19.4	0.8
4		Single family home with central forested block	*0.57*	17.0	3.8	2.9	2.7
5		Multi-housing units, up to 4 floors	*0.70*	0.4	2.3	3.8	0.9
6		Multi-housing units, more than 4 floors	*0.75*	0.0	0.0	0.0	0.0
7		Multi-housing units with green sidewalk and grenn roofs	*0.48*	0.0	0.0	0.0	8.8
8		Residential or suburban	*0.59*	1.9	0.5	0.3	0.4
9		Closed neighborhood	*0.48*	6.8	9.2	6.2	6.2
10		Commercial and business areas	*0.60*	0.0	0.2	0.2	0.2
11		Incipient and irregular settlements	*0.56*	0.1	0.0	0.0	0.0
12		Consolidated and irregular settlements	*0.70*	0.9	0.0	0.0	0.0
13		Industrial not very dense	*0.70*	0.6	1.2	1.2	1.2
14		Industrial dense	*0.80*	0.8	1.3	1.8	1.3
15		Pasture / meadow / lawn clay loam soil	*0.30*	19.7	7.9	8.4	4.9
16		Bare soil compacted	*0.63*	12.1	13.4	6.7	12.9
17		Extensive crops	*0.21*	0.0	0.0	0.0	0.0
18		Traditional horticultural crop	*0.20*	0.3	0.0	0.0	0.3
19		Agro ecological horticultural crop	*0.19*	0.0	0.0	0.0	0.0
20		Forestry: Dense forests	*0.13*	0.8	0.8	0.8	5.7
21		Forest (more than 50% of the land covered)	*0.23*	1.3	2.4	2.4	6.7
22		Forest (less than 50% of the land covered)	*0.33*	13.4	13.6	10.2	14.5
23		Sparse vegetation (not compacted by human activity)	*0.44*	10.8	8.0	5.9	6.0
24		Brick factory	*0.63*	0.0	0.0	0.0	0.0
25		Brick factory with scattered buildings	*0.74*	0.4	0.0	0.0	0.0
26		Landfills	*0.63*	0.0	0.0	0.0	0.0
27		Watercourses, land deposits	*1.00*	1.6	1.6	1.6	1.6
28		Sports equipment on forested land	*0.30*	0.2	1.0	1.5	1.0
		Average Runoff Coefficient		0.49	0.53	0.58	0.49

In urban drainage design, given a probability of exceedance of 20% (return period of 5 years), the new probability of exceedance reach the value 1.9 * 20% ≈ 38% (a new return period of 2.6 years). For the scenario 2 (extreme waterproofing), the runoff coefficient reaches a value of 0.58, which represents approximately an increase of 18% from its current value. Applying equation (4) for $C_{t+1}/C_t = 1.18$ would lead to an equivalent ratio $P_{t+1}/P_t \approx 4$. Given a probability of exceedance of 20%, the new probability of exceedance reach the value of 80% and a new return time is about 1.25 year. This situation will make necessary a strong reinvestment in urban drainage infrastructure only to keep the status of protection under current conditions. For the Scenario 3 with increased GI the runoff coefficient keeps the current value of 0.49. Even though the security conditions are the same, the situation represents a future scenario with major population and more efficient urbanization. These values imply significant improvements for the population.

4. Conclusions

The proposed methodology allows quantifying improvements in urban drainage systems with an increase of GI, in terms of flooding risk reduction. The results shown that the moderate and severe waterproofing scenarios produce an increased risk of flooding from 1.9 times to 4 times, respectively. On the contrary the green scenario keeps the current security conditions but including the major increases in population and urbanization. Improving the GI constitutes a strong strategy to adapt to climate and urban changes. Floodplains should be protected by urban regulations as green spaces to assure its hydrological functionality which will reduce flood risk. This methodology can be applied in different urban basin and provides a way to quantify improvements in the safety of the population concerning urban flooding by increasing of GI.

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