Impact on urban drainage taking into account the rainwater harvesting in a rural district

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***Abstract*—** Climate change is a reality in which we are all immersed, this situation generated by environmental problems, affects the rainfall that occurs in different parts of the world. These, increase on a large scale that even cause material damage in addition to human losses. Given this context, this research focuses on the collection of rainwater as a strategic means that will favor a rural district which presents intense rainfall, in addition to being one of the most affected by rains within the regions of Peru, through Said collection proposal will reduce the drainage flow that causes disasters to the population. The methodology of this study is made up of three stages. We begin with the characterization of the study area. Then, stage two is developed, which consists of hydrological modeling. Finally, the third phase consists of determining the volumes of water captured due to the runoff of precipitation on the roofs of houses, green areas and pavements. Resulting in a 3.15% decrease in the drained volume, which corresponds to the collection of reservoirs with a capacity of 400 liters/day in each house. Likewise, when the study area increases its socioeconomic level, reservoirs with a capacity of 875 liters/day can be integrated in each house, thus having a 6.89% reduction in the volume drained.

Keywords*— *Precipitation, Rain, Estimate, ArcGis, Collection, Urban drainage.

I. INTRODUCTION

Water is one of the resources affected by the conditions imposed by climate change, mainly in relation to its availability. The increase in global temperature is triggering the increase in precipitation. [1] Ministry of the Environment, “Peru and Climate Change: Peru's Third National Communication to the United Nations Framework Convention on Climate Change”. [2] In 2012, the World Water Resources Assessment Program, after water management in a context of uncertainty and risk, found that Peru showed regions with upcoming physical water scarcity and economic water scarcity, according to the list half of the countries in the world with this problem. Large water currents have a drag energy that increases according to intense rains that occur in the sector.

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Management of rainwater collection and treatment can play an important role in adaptation to climate change, having a safer sustainability and a reduction in energy costs in construction and maintenance of urban infrastructures. During rainy season, in some cities of the country, floods associated with:

- Natural phenomena of extraordinary rainfall.
- Lack of control mechanisms for water masses.
- Increase in the impermeable area of cities.

Urbanization has increased impervious areas, so developed urban areas have lost rainwater storage and infiltration functions, resulting in floods and droughts. [3] Technical-economic feasibility study of the collection and treatment of rainwater in urban areas.

Previous studies denote that urban areas in many cities are prone to a collapse in their drainage systems, abruptly affecting everything in its path, such as homes, sections of roads, works of art and hydraulics and sanitary infrastructure. Cajamarca is one of the regions with highest number of emergencies caused by heavy rains due to impact of climate change. [1] Ministry of the Environment, “Peru and Climate Change: Peru's Third National Communication to the United Nations Framework Convention on Climate Change”.

For this reason, the present investigation examines impact on urban drainage, taking into account roof rainwater harvesting of houses and green areas of the village in district of Jesus, department of Cajamarca, analyzing it for maximum historical rainfall of 74.1 mm.

II. METHODOLOGY

Study area is located in Cajamarca department, district of Jesús - Peru. It has an altitude of 2,564 meters above sea level, and 439,677 m² area. As a first step, the study area was sectorised into 50 quadrants., as shown in Fig. 1.

Fig. 1. Sectoring of study area into 50 quadrants. (Google Earth)

A. *Identification of roofing materials types*

Once study area has been established, data is extracted taking into account the coordinate system. Peru is located in southern hemisphere in zones 17, 18 and 19. Likewise, projection of the Universal Transverse Mercator Coordinate System (UTM) is selected, World Geodetic System 1984 (WGS-84) will be used and zone 17 south will be chosen, where the Jesus district is located.

Obtaining numerical roof areas is very important, since it is basis for estimating volume of rainwater that will be collected. In this study, manual digitization method was used, which consists of drawing roof areas in ArcGIS based on satellite images of Jesus district, which will be distributed in quadrants as mentioned above.

Polygons will be georeferenced with previously named coordinates. Drawing of the polygons will adopt the shape of houses roofs in the district of Jesus. This step will be repeated in each delimited quadrant, to obtain the data of the areas of each roof as shown in Fig. 2. ArcGIS software results in area charts with the 50 quadrants data, they will be recorded on a sheet calculation to estimate total catchment area of Jesus district.

Fig. 2. Quadrant roof areas delimitation

Evaluation of roof materials types, is established respecting quadrants organization to have a classification of influence by the material type in an orderly manner, shown in Fig. 3. Respective material for each area is corroborated, making use of video recorded tour of the Jesus district provided by Google Maps Street View, however, images provided by the application are from 2013, so there is currently a variation due to new constructions and possible roof changes, consequently, classification is not 100% accurate.

Fig. 3. Roofing materials types in Jesus district

Having visual representation of roofs distribution by type of material, we proceed to quantify total amount of catchment area shown in Table I. This information is used to determine total catchment flow taking into account coefficient of respective runoff for each material.

TABLE I. *Area by material type*

TYPE OF MATERIAL	AREA (m^2)
Roof tile	26,436.00
Concrete	15,624.00
Calamine Met/Plast	67,512.00

B. *Drainage areas delimitation*

It is important to identify the surfaces through which the precipitation flows, as this makes it possible to determine the drainage flow corresponding to roofs, pavements and green areas (gardens, orchards and parks), which are the main area of influence through which the water runoff affects inhabitants of Jesus district. For this reason, drainage areas were delimited in ArcGIS to quantify data as shown in Table II, and to determine their percentage of influence, as shown in Fig. 4.

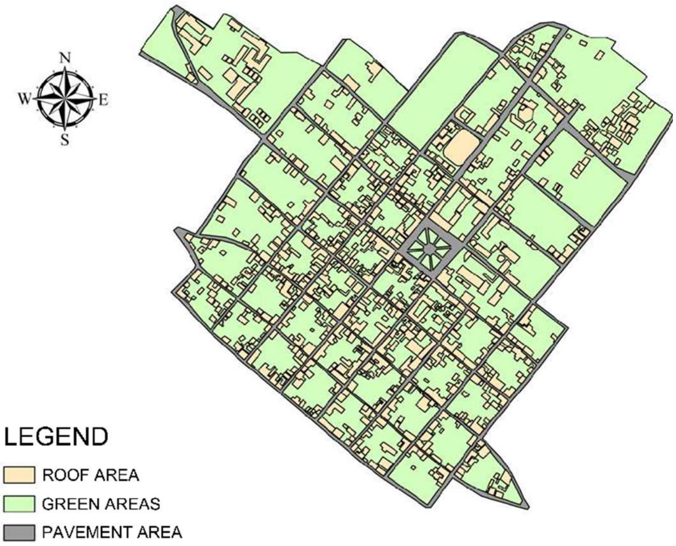

Fig. 4. Drainage areas- Jesús district

TABLE II. *Drainage areas*

INFLUENCE SURFACE	AREA (m²)	PERCENTAGE
Roofs	109,573.00	25%
Pavements	58,770.00	13%
Green Areas	271,334.00	62%
TOTAL	**439,677.00**	**100%**

C. Precipitation-runoff equations

Taking areas of influence value, it is identified which part of total precipitation will generate direct runoff. Equations determine flow that can be captured from rain on the houses roofs and drainage that is linked to flow that runs off green areas and pavements.

For rainwater flow collected from the roofs, the method corresponding to the [6] Design Guide for rainwater harvesting, developed by the Pan-American Center for Sanitary Engineering and Environmental Sciences "CEPIS" is used to calculate volume of water that will fulfill domestic supply purpose or another that the user assigns. Runoff coefficients shown in Table III must be taken into account.

TABLE III. Roof Runoff Coefficients

SURFACE	RUNOFF COEFFICIENT
Metal or plastic sheeting	0.9-0.95
Concrete	0.8-0.9
Clay roof tiles	0.8 - 0.9
Wood	0.8 - 0.9
Straw	0.6 - 0.7

[7] Design guide for rainwater harvesting (CEPIS)

For this study, 74.1 mm maximum historical rainfall occurred on March 12, 2009 captured by the San Juan Meteorological station and the area according to the type of roofing material with its respective runoff coefficient is used. Equation established by CEPIS to calculate the water supply is:

$$A_i = \frac{P_{p_i} \times C_e \times A_c}{1000} \tag{1}$$

Donde:

P_{p_i} : Average monthly precipitation (lit/m²)
C_e : Runoff coefficient
A_c : Catchment area (m²)
A_i : Water supply (m³)

Supply water obtained will be affected by concentration time, obtained through formulas (3) and (4). In this way, flow will be obtained in m³/s, for its subsequent analysis.

On the other hand, flows of green areas and pavements will have a different analysis. An average of 4 methods corresponding to the [4] Manual of Hydrology, Hydraulics and Drainage, developed by Ministry of Transport and Communications -MTC is used, methods will be described interpreting the equations for maximum flow calculation.

Curve Number Method

Knowing amount of precipitated rain, runoff generated can be obtained by the following mathematical expression [5]:

$$Q = \frac{(I - 0.2 \times S)^2}{I + 0.8 \times S} \tag{2}$$

Where:

Q : Runoff (mm)
I : Intensity (mm/h)
S : Potencial maximum difference between rainfall and generated runoff $S = \frac{25.400}{N} - 254$
N : Curve number, obtained by table

Concentration time must also be determined to obtain value of peak flow per unit of drainage area in m³/s/mm/km², interpolating with respect to determined concentration times. The average of the following formulas is used:

- Kirpich formula

$$T_c = 0.0078 \left(\frac{L^{0.77}}{S^{0.385}}\right) \tag{3}$$

Where:

T_c: Concentration time (min)
L : Main channel length (m)
S : average terrain slope (%)

- California Cultiverts Practice formula

$$T_c = 60\left(\frac{0.87075 \times L^3}{H}\right)^{0.385} \quad (4)$$

Where:

T_c : Concentration time (min)
L : Main channel length (km)
H : Height difference (m)

Maximum flow is calculated with:

$$Q_{max} = q \times Q \times A \quad (5)$$

Where:

Q_{max} : Maximum flow (m³/s)
q : Peak flow per unit area (m³/s/mm/km²)
Q : Runoff (mm)
A : Total area of influence (Km²)

Rational Method

Estimates maximum flow taking into account precipitation, encompassing all the abstractions in a single estimated runoff coefficient based on characteristics of study area, based on the following expression [4] Manual of Hydrology, Hydraulics and Drainage, developed by Ministry of Transport and Communications -MTC:

$$Q = 0{,}278\ (C \times I \times A) \quad (6)$$

Where:

Q : Maximum design discharge (m³ /s)
C : Runoff coefficient
I : Maximum hourly precipitation intensity (mm/h)
A : Influence area (Km²)

Concentration time must be determined to obtain intensity. Average is used from formulas that are described in (3) and (4).

The established maximum precipitation is used to be divided by the concentration time and determine the Intensity which is illustrated in the following equation:

$$I = \frac{PP}{T_c} \quad (7)$$

Where:

I : Maximum hourly precipitation intensity (mm/h)
PP : Maximum corrected precipitation (mm)
T_c: Concentration time (hours)

Runoff coefficient must be obtained, taking into account vegetation cover in the area, type of soil and slope. [5, page 50] Manual of Hydrology, Hydraulics and Drainage of MTC-Peru.

Temez Modified Rational Method

It is rational method according to formulation proposed by Témez (1987, 1991) adapted for climatic conditions of Spain. And it allows to easily estimate peak flows. It assumes that rain is uniform in time (constant intensity) which is only true when the duration of the rain is very short. In addition, concentration times (Tc) are between 0.25 and 24 hours, the formula is as follows [4] Manual of Hydrology, Hydraulics and Drainage, developed by Ministry of Transport and Communications -MTC:

$$Q = 0{,}278\ (C \times I \times A \times K) \quad (8)$$

Where:

Q : Maximum design discharge (m³ /s)
C : Runoff coefficient for the interval in which I occurs
I : Maximum hourly precipitation intensity (mm/h)
A : Area of influence (Km²)
K : Uniformity Coefficient

The formulas that define the factors of the general formula are the following:

- Concentration time (Tc)

$$T_c = 0.3\left(\frac{L}{S^{0.25}}\right)^{0.76} \quad (9)$$

Where:

L : Main channel length (km)
S : Average slope of the main channel (m/m)

- Coefficient of Uniformity (K)

$$K = 1 + \frac{T_c^{1.25}}{T_c^{1.25}+14} \quad (10)$$

Where:

T_c : Concentration time (hours)

- Simultaneity Coefficient or Reduction Factor (K_A)

$$K_A = 1 - \left(\log_{10}\frac{A}{15}\right) \quad (11)$$

Where:

A : Influence area (Km²)

- Precipitación máxima corregida sobre la cuenca (P)

$$\mathrm{P} = K_A \times P_d \tag{12}$$

Where:

K_A : Reduction factor
P_d: Maximum daily precipitation (mm)

- Precipitation intensity (I)

$$I = \left(\frac{P}{24}\right) \times (11)^{\frac{28^{0.1}-T_c^{0.1}}{28^{0.1}-1}} \tag{13}$$

Where:

P : Maximum corrected precipitation (mm)
T_c: Concentration time (hours)

- Runoff Coefficient (C)

$$C = \frac{(P_d-P_o)\times(P_d+23\times P_o)}{(P_d+11\times P_o)^2} \tag{14}$$

Where:

P_d : Maximum daily precipitation (mm)
P_o : Runoff threshold = $\left(\frac{5000}{CN}\right) - 50$
CN: Curve number

Value of the curve number must be obtained, depending on type and use of the land. [3, page 47] Manual of Hydrology, Hydraulics and Drainage.

<u>Synthetic Unit Hydrograph Method</u>

In addition to natural hydrographs, there are synthetic hydrographs that are simulated, artificial, and obtained using the physiographic characteristics and parameters of interest area. Its purpose is to represent or simulate a representative hydrograph of basin hydrological phenomenon, to determine design peak flow [4] Manual of Hydrology, Hydraulics and Drainage, developed by Ministry of Transport and Communications -MTC.

$$Q_p = 0.208\left(\frac{h_{pe}\times A}{t_p}\right) \tag{15}$$

Where:

Q_P : Peak flow (m³/s)
h_{pe} : Effective or excess precipitation (mm)
A : Influence area (Km²)
t_p : Peak occurrence time (hours)

Concentration time must be determined to obtain intensity. Average is used from formulas that are described in (3) and (4).

The formulas that define the factors of the general formula are the following:

- Peak occurrence time (t_p)

$$t_p = \sqrt{t_c} + 0.6t_c \tag{16}$$

Where:

t_c : Concentration time (hours)

- Base time (t_b)

$$t_b = 2.67t_p \tag{17}$$

Where:

t_p : Peak occurrence time (hours)

- Delay time (t_r)

$$t_b = 0.6t_c \tag{18}$$

Where:

t_c : Concentration time (hours)

- Effective or excess precipitation (hpe)

$$t_b = PP - Po \tag{19}$$

Where:

PP : Maximum corrected precipitation (mm)
P_o : Direct runoff (mm)

D. Drainage triangular channel flow

Ditches are lined or unlined, longitudinal ditches opened in the ground, located on both sides or one side of the road, in order to adequately capture, conduct and evacuate surface water flows. [5] Manual of Hydrology, Hydraulics and Drainage, developed by Ministry of Transport and Communications -MTC

To calculate flow, Manning's formula is used,

$$Q = \frac{A^{5/3}\times Se^{1/2}}{\eta\times Pe^{2/3}} \tag{20}$$

Where:

A : Hydraulic area (m²)
Se: Pending
η : Manning coefficient
Pe : Wetted perimeter (m)

The formulas that define the factors of the general formula are the following:

- Hydraulic area (A)

$$A = \frac{Z \times Y^2}{2} \quad (21)$$

Where:

Z : Slope inclination
Y : Depth (m)

- Wetted perimeter (Pe)

$$Pe = Y \times \sqrt{(1 + Z^2)} \quad (22)$$

Donde:

Z : Slope inclination
Y : Depth (m))

III. RESULTS

A. Roof areas flow

After distributing 50 quadrants into 10 groups to facilitate calculations of supply with respect to catchment that roofs have, amount that runs off roofs of houses is determined. An endowment of 50 liters/person/day recommended by [5] DIGESA is established, expressed in the Manual of Drinking Water Projects in Rural Populations, developed by the Peru-Germany Debt for Development Fund -FPA. Likewise, surveys were developed to determine number of inhabitants per house, giving an average of 6 people per house. Two drums of 200 liters are used to cover the water supply for domestic use required, in this way it is determined that the maximum supply for each house is 400 liters/day, a flow that will be retained and discounted from the total flow that runs through roofs. The remaining offer becomes drainage flow, which becomes part of the total runoff of the study area, in a concentration time of 0.219 hours, this analysis is presented in Table IV.

TABLE IV. Distribution of daily flows

N° Cluster	Supply (litres/hour/day)	N° Houses	Endowment (litres/day)	Collection (litres/day)	Drainage (litres/day)
1	193509	70	400	28000	165509
2	128700	89	400	35600	93100
3	178846	73	400	29200	149646
4	170244	109	400	43600	126644
5	150960	81	400	32400	118560
6	128700	90	400	36000	92700
7	172812	71	400	28400	144412
8	183722	94	400	37600	146122
9	141030	76	400	30400	110630
10	120941	71	400	28400	92541
Total	**1569464**	**824**		**329600**	**1239864**

When estimating the entire flow of water from the supply of the roofs, it is converted to the units of m³/s as observed in Table V, in the same way for the remaining drainage, shown in Table VI to proceed with a calculation homogeneous considering the drainage flow that corresponds to the green areas and pavements.

TABLA V. *Runoff roof flow*

Qoffer (m³/hour)	1569
Qoffer (m³/min)	26.158
Qoffer (m³/s)	0.436

TABLA VI. *Drainage rate remaining from roofs*

Qserver system (m³/hour)	1240
Qserver system (m³/min)	20.664
Qserver system (m³/s)	0.344

B. Green areas and pavements Flow

In the development of each method, it is important to determine length of surface, difference in level and average slope of the terrain in study area, average was made with the critical values for each data, these values are expressed in Table VII.

TABLA VII. *Geometric data of the study area*

Length (m)	995.73
Slope (%)	4%
Level difference (m)	44.3

Likewise, values of curve number for green areas and pavements are 55 and 90 respectively. Then we proceed to replace data in the formulas already presented for each method, in this way results are in Table VIII, where 25% of roofs, 13% of pavements and 62% of green areas were considered.

TABLA VIII. *Average Qmax result*

Method Curve number	2.77
Rational Method	13.25
Témez's Modified Rational Method	2.18
Synthetic Unit Hydragram Method	6.84
Qmax average (m3/s)	**3.93**

C. Total Drain Flow

Total drainage flow will be sum of remaining drainage flow of roofs and green areas and pavements, having a total of 4,274 m³/s. However, Jesus district presents triangular ditches on the side of the roads as illustrated in Fig 5. The MTC establishes the minimum dimensions according to rainfall conditions, since study area is in a rainy region, minimum depth will be 0.3 m and 0.75. width. On the other hand, the slope will be 4% and the ditches being concrete, the Manning coefficient is 0.014.

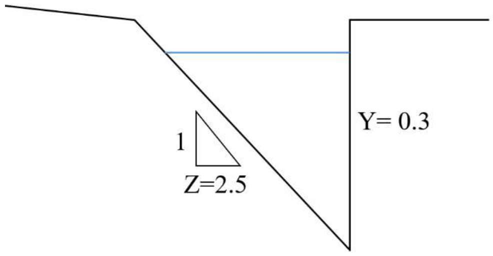

Fig. 5. Triangular ditch typical section

These works of art generate a reduction in runoff, which is why retained flow is calculated, being 0.436 m³/s with a section area of 0.1125 m².

IV. VALIDATION

The present study shows how the collection of rainwater on roofs affects, in a positive way, compared to the runoff generated by precipitation, which causes unforeseen events due to the masses of water that are produced.

Three cases are analyzed. In the first case, collection of rainwater on the roofs will not be taken into account. Consequently, drainage flow will only be drained by the ditches, which has a length of 10227.4 m and a section area of 0.1125 m². With these values it will be possible to calculate drainage capacity in m³. Results are presented in Table IX, to have a better understanding, in both cases calculations are presented in volumes to appreciate how much is generated and drained.

TABLA IX. *Total volume in study area – Case 1*

Surface type	Volume (m³)
Vol Sewer system (Roof area)	343.713
Vol Sewer system (Green areas and Pavements)	3098.412
Vol drainage capacity (Ditches)	1150.583
Vol Not drained	**2291.542**

In the second case, the collection of rainwater on roofs, green areas, pavements and gutters will be taken into account, which are expressed in Table X.

TABLA X. *Total volume in study area – Case 2*

Surface type	Volume (m³)
Vol Sewer system (Roof area)	343.713
Vol Sewer system (Green areas and Pavements)	3098.412
Vol Detained (Endowment 400 liters/day/house)	**72.182**
Vol Drainage Capacity (Ditches)	1150.583
Vol Not drained	**2219.360**

It is shown that collection of rainwater decreases volume of water that runs off. Taking into account an additional analysis, if socioeconomic level of study area were medium or high, it would be considered an urban area, where houses would have cisterns with capacities of 750 to 1000 liters/day, with an average of 875 liters/day. Consequently, there would be a greater collection and reduction of rainwater in drainage as shown in Table XI.

TABLA XI. *Total volume in study area – Case 3*

Surface type	Volume (m³)
Vol Sewer system (Roof area)	343.713
Vol Sewer system (Green areas and Pavements)	3098.412
Vol Detained (Endowment 875 liters/day/house)	**157.899**
Vol Drainage Capacity (Ditches)	1150.583
Vol Not drained	**2133.643**

On the other hand, it is a fact that population growth leads to generating construction of new buildings in the Jesus district, consequently there will be an increase in impervious area which generates a greater runoff flow. This means that green areas decrease, for this reason a percentage variation of surfaces was made. Area variable is modified, initially 25% of roof area is maintained and it continues to increase 5% up to 50%, where the green areas will decrease proportionally according to the increase in said percentage. Taking this analysis into consideration, Tables XII to XVII were generated, which represent average maximum flows without taking into account high peaks.

TABLA XII. *With 25% roofs and 62% green areas*

Method Curve number	2.77
Rational Method	13.25
Témez Modified Rational Method	2.18
Synthetic Unit Hydragram Method	6.84
Qmax average (m3/s)	**3.93**

TABLA XIII. *With 30% roofs and 57% green areas*

Method Curve number	2.63
Rational Method	12.41
Témez Modified Rational Method	2.07
Synthetic Unit Hydragram Method	6.40
Qmax average (m3/s)	**3.70**

TABLA XIV. *With 35% roofs and 52% green areas*

Method Curve number	2.49
Rational Method	11.58
Témez Modified Rational Method	1.96
Synthetic Unit Hydragram Method	5.97
Qmax average (m3/s)	**3.47**

TABLA XV. *With 40% roofs and 47% green areas*

Method Curve number	2.35
Rational Method	10.75
Témez Modified Rational Method	1.84
Synthetic Unit Hydragram Method	5.54
Qmax average (m3/s)	**3.24**

TABLA XVI. *With 45% roofs and 42% green areas*

Method Curve number	2.21
Rational Method	9.98
Témez Modified Rational Method	1.73
Synthetic Unit Hydragram Method	5.10
Qmax average (m3/s)	**3.02**

TABLA XVII. *With 50% roofs and 37% green areas*

Method Curve number	2.08
Rational Method	9.10
Témez Modified Rational Method	1.61
Synthetic Unit Hydragram Method	4.67
Qmax average (m3/s)	**2.74**

Taking quantitatively maximum flows, we proceed to graph to see its trend. In Fig 6 it is evident that, when percentage of roof area of houses increases, flow of green areas and pavements decreases. However, as there is a greater amount of impermeable area, runoff will increase, but since there is no certainty of type of material that will be used, runoff value to be produced cannot be accurately determined.

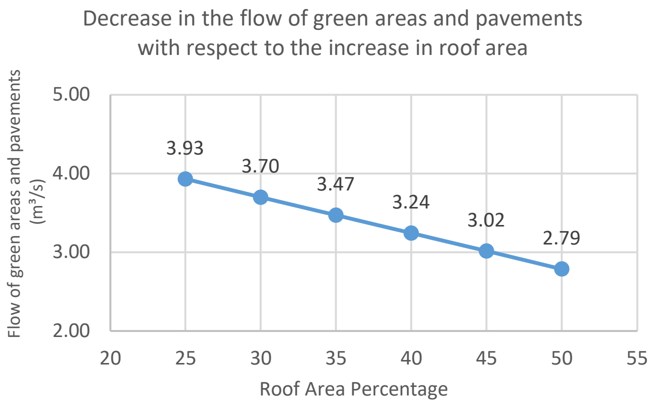

Fig. 6. Drainage flows of green areas and pavements

V. CONCLUSIONS

By collecting rainwater, it is possible to supply domestic water to buildings and, at the same time, decrease runoff volume.

It is concluded that collection of rainwater in Jesus district, can decrease 3.15% of total runoff volume, having an endowment of 400 liters/day/house and 6.89% having an endowment of 875 liters/ day/house.

Increasing impervious areas allows reducing runoff flow of green areas, from having 3.93 m^3/s considering 25% roofs and 62% green areas to 2.79 m^3/s considering 50% roofs and 37% green areas, which increases runoff amount down the streets.

Increasing collection of rainwater and preserving and increasing green areas, reduces the impact of overflow in the city's drainage.

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