Methodology for Selecting Rainwater Recycling Systems for Small Scale Residential Constructions

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ABSTRACT

Methodologies for the selection of the more efficient rainwater recycling systems was proposed for small scale constructions in Colombia. Even though different policies in Colombia aim for the rainwater systems implementation, as well as several design guides and installation manuals are available, there is still uncertainty among engineers and policy makers. There is no record of any methodology to select a rainwater recycling system for small scale residential constructions. This study proposes a methodology based on key variables involved in the design of rainwater recycling systems such as structure's architecture, hydrology and socioeconomic level. Variables such as impermeable area of the roof were also considered. Selecting the most efficient rainwater recycling system was performed through a multi-criteria decision matrix, which assigns different weights to each identified variable. The methodology was verified by evaluating fifty different scenarios, modifying rain data and constructive features. This study concludes that the application of multi-criteria matrix is effective in the selection of a suitable rainwater reuse system based on the results from the modeled scenarios, and represents a useful tool to facilitate decision-making processes for designers and administrative planning entities.

KEYWORDS

Rainwater, Recycling, Methodology, Multi criteria matrix

INTRODUCTION

Rainwater recycling systems is gaining new interest in big cities, where high densification and increasing demand for goods and services, represent a big challenge for planning entities. In addition, climate change and illegal settlements generates a real social issue, especially in developing countries. Mostly half of world's population lives in cities (UDNP, 2015), and this phenomenon is not different in Colombia, where high urbanization was evidenced since 1950´s (Roldan,2009); according to The World Bank between 1960 and 2017 the percentage of total population that moved from rural areas to cities passed from 46 to 80 percent.

Since 2014 Colombia is one of the countries that have included sustainable development goals on its government agenda. According to the sixth sustainable development goal: Clean Water and Sanitation, rainwater recycling is an important practice to accomplish this objective.

Rainwater recycling benefits are well known to reduce urban runoff, provide additional water supply, save energy, and provide resiliency (ASCE, 2010). Recycling systems are a common practice in developed countries (Kahinda, Taigbenu, Boroto, 2007), since an alternative water supply system diminishes pressure on water sources (Notaroa, Liuzzoa, Frenia, 2016). In Latin America, countries like Mexico already have implemented those systems as an alternative in drought regions with no water supply infrastructure.

Water demand in Colombia

Domestic water demand in Colombia corresponds to almost nine percent from the total water availability (ENA,2014). At small scale residential constructions, toilet flushing represents second highest uses per person (EA,2010), demand that could be potentially satisfied by rainwater. Most of the water demand in Colombia – 67 percent – is concentrated in the west-center of the country, in Magdalena´s and Cauca´s hydrographic area. This area accounts for 24 percent of country's entire surface, and houses around thirty million people. Farmers also benefit from this territory, where 70 percent of total agricultural goods are produced (IDEAM-Cormagdalena,2001). Moreover, recent climate changes, where drought are becoming common, increase uncertainty over water supply sources in Colombia in future years.

Colombia is classified as one of the countries with highest water yield around the world, it accounts with a national production of 56 liters per second per square kilometer; this value is higher than world´s media - 10 L/s km² - and Latin America value - 21 L/s km² (Oferta de agua, IDEAM, 2018).

Rainwater Recycling Systems

Gravity System

System based on collection and storing of rainwater from roof at an elevated tank, usually located at loft, allowing water to take advantage of gravity to flow (EA, 2010). Gravity systems depends on structural conditions, so that the construction could bear tank´s weight (The Suds Manual, CIRIA 2015). Figure 1 shows a typical installation of this system.

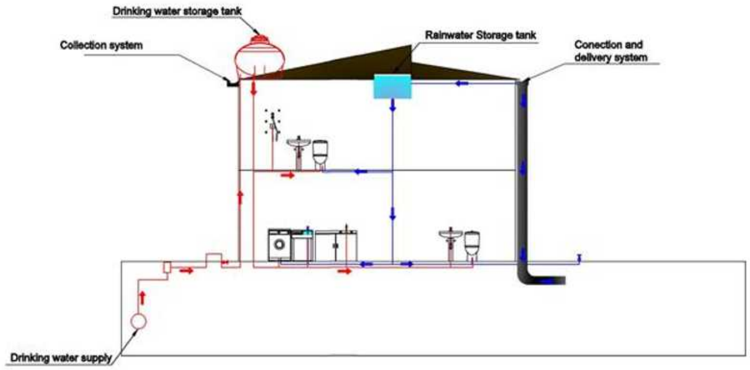

Figure 1. Gravity System scheme

Pumped System

This rainwater recycling system collects water by gravity on underground or ground tanks. For tanks installation depends on space availability. Stored water could be pumped in three different ways:

Direct pumping system with underground tank: Rainwater is pumped directly to units where it will be used (EA, 2010), as it could be seen in Figure 2. Underground tanks, usually on gardens, store rainwater collected from roofs. Tank sizing depends on roof area and precipitation parameters.

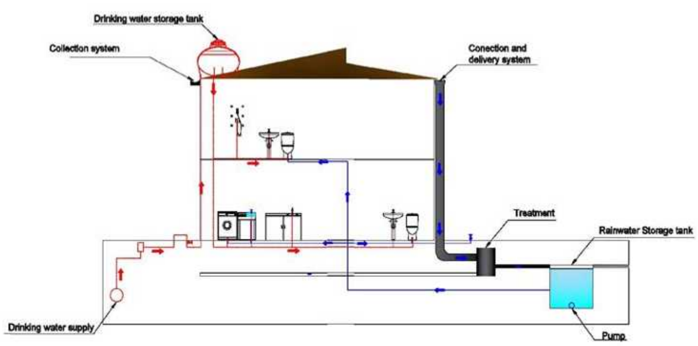

Figure 2. Pumped System scheme

Direct pumping system with vertical tank: This system varies respect to previous one on storage tank. In this case, vertical tank is used. Vertical tank is an option when there are no available areas to install underground tank, because it could be located on ground level. Nevertheless, vertical tanks storage volume is lower than underground tanks as it could be seen in Figure 3.

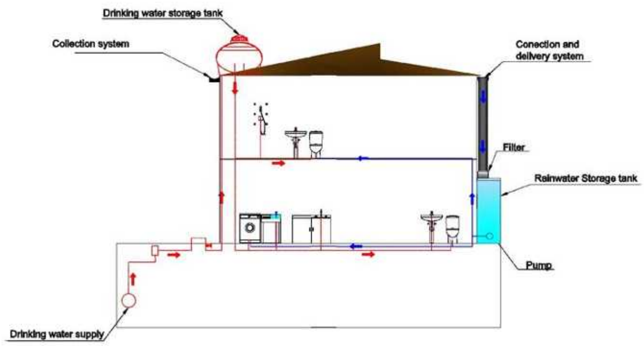

Figure 3. Pumped System with Vertical Tank scheme

Combined pumping system: Water collected from roof goes straight to headed tank, excess runoff flows by gravity to underground tank. When water level in headed tank is low, pumping system activates to fill it. Combined pumping system is shown in Figure 4.

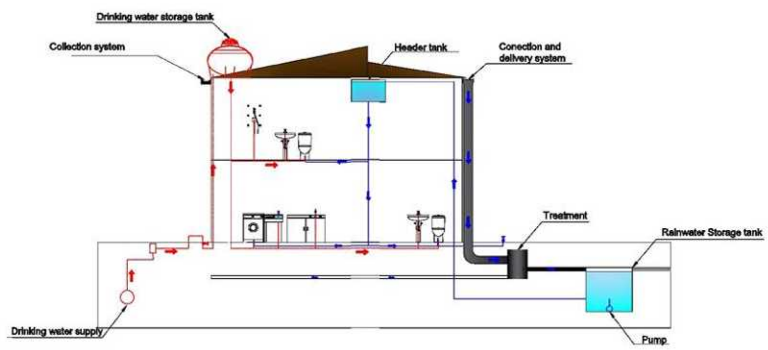

Figure 4. Combined Pumping System scheme

METHODOLOGY

Multi-criteria matrix

A matrix was performed evaluating different rainwater recycling methods scenarios in Colombia. Matrix purpose is to be a useful tool for selecting a rainwater recycling system for small scale constructions designer. Five different parameters were taken into account for matrix: *annual precipitation (P), garden area (GA), loft existence (L), socioeconomic level (SL) and roof area (R).*

Annual precipitation refers to multi-year average precipitation; in Colombia that information could be get from IDEAM -Institute of Hydrology, Meteorology and Environmental Studies-. For research purposes, five cities in different states were selected to obtain rainfall data

(Figure 5). Results are shown in Table 1. This parameter allows to calculate how much water could be store in one year and enable to identify region with high rainwater recycling potential.

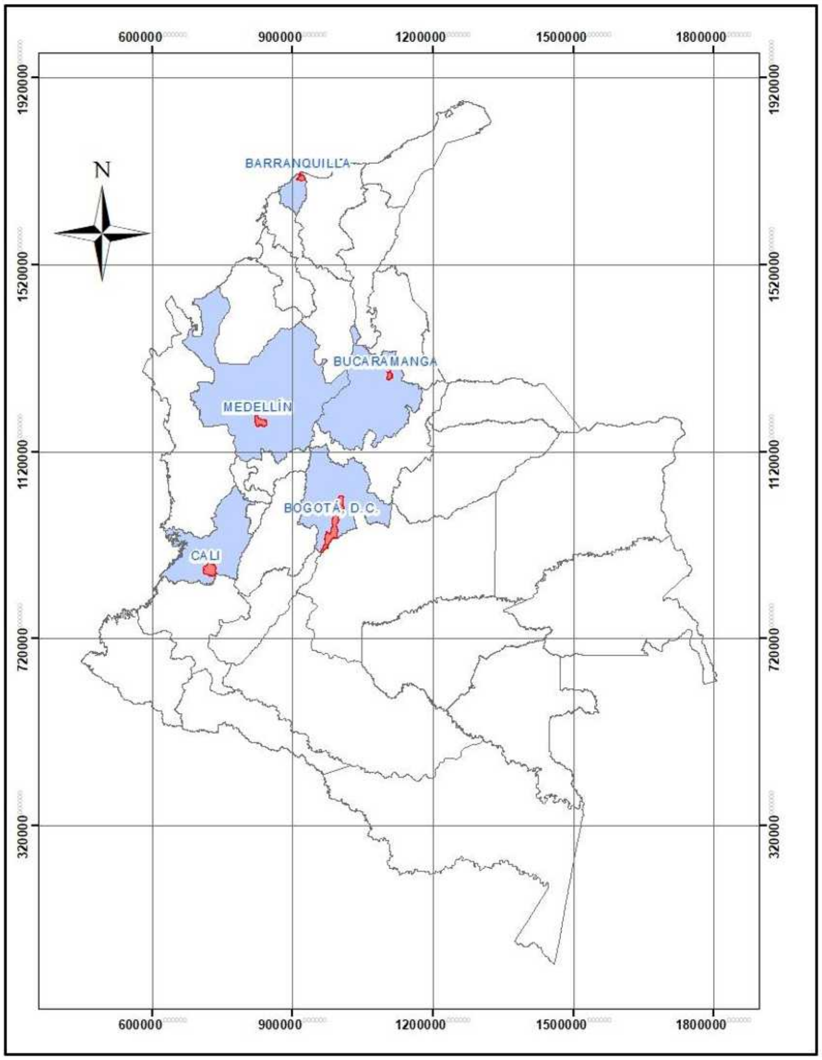

Figure 5. Selected cities for research

City	State	Multi-year average Precipitation (mm)
Bogotá	Cundinamarca	878
Medellín	Antioquía	1765
Cali	Valle del Cauca	1445
Barranquilla	Atlántico	742
Bucaramanga	Santander	1314

Table 1. Multi-year average precipitation (mm) in Colombian cities

Figure 6 shows monthly multi-year average precipitation for selected cities. Four of the five cities have a bimodal precipitation behavior with two periods, each period is marked by drought and rain. Behavior of city Barranquilla is different from the other cities, but it's also bimodal (Guzman, Ruiz, y Cadena 2014). Precipitation in Colombia varies from region to region, according to topography and global atmospheric processes, in order to allow hydrological cycle regulation (Cuartas y Poveda 2002). Rainwater recycling systems have great potential in most regions of Colombia, because of precipitation events throughout the entire year.

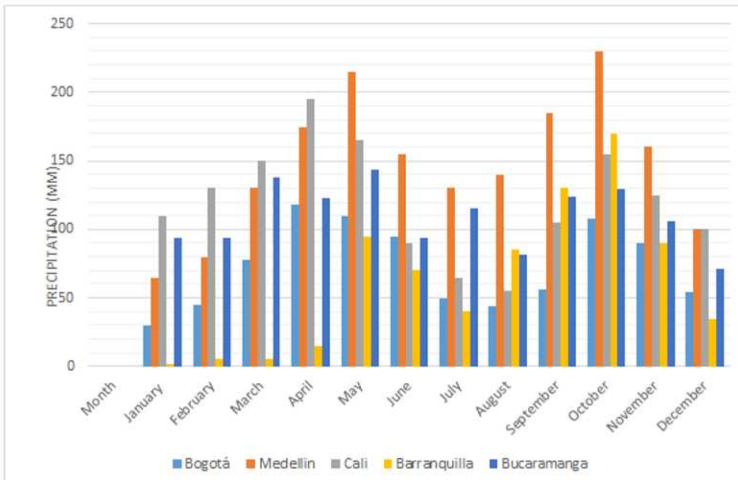

Figure 6 Multi-year average precipitation

Garden Area is an important parameter to establish the underground tank installation facility. Typical garden area was defined as five square meters, enough to install five thousand liters underground tank. Three options were proposed for this parameter: garden area bigger than 5 m²; garden area smaller than 5 m²; and no garden area.

Loft is a vital space for placing headed tank for gravity and combined systems. At low socioeconomic level constructions loft does not exist, enough space between floor and roof could be accepted. Loft existence was performed as a Yes/No parameter.

Socioeconomic level is a relevant aspect to analyses when designing rainwater recycling systems. Higher socioeconomic level, higher investment. Values from 1 to 6 are taken for this parameter. The matrix enables to assess relation between buyer's economic capacity and chosen rainwater recycle system.

Roof Area determines tanks sizing and volume of precipitation that could be used for recycling. For small scale constructions, range between 50 and 200 square meters was established.

Fourth different matrix were performed for each kind of recycling system. Weights of every parameter for each system are shown in table 2. Weights were determined according to each system requirements. Parameters take values between 1 to 3, allowing so to be 1.0 the lowest score and 3.0 the highest. System with higher rating will be chosen. Percentages were subjectively chosen by the authors, so that systems needs were achieved.

Criteria	Gravity	Pumped - Underground Tank	Combined	Pumped - Vertical Tank
P	20%	15%	15%	40%
GA	5%	30%	20%	25%
L	35%	10%	20%	5%
SL	20%	20%	25%	20%
R	20%	25%	20%	10%

Table 2. Multi-criteria matrix Weights

Scenario Testing

Fifty different scenarios were tested for matrix validation. Ten scenarios per city, varying GA, L, SR and L; Precipitation was the only parameter that stayed the same in all scenarios for each city. Scenarios were thinking to simulate small scale constructions conditions, houses at different social levels specifically. Testing scenarios were proposed knowing in advance either circumstances at which recycling systems may be appropriate or not.

RESULTS

CASE	CITY	MULTI-YEAR AVERAGE PRECIPITATION (mm)	GARDEN AREA (m²)	LOFT EXISTENCE	SOCIOECONOMICAL LEVEL	ROOF AREA (m²)	Gravity System	Direct Pumping System with underground tank	Direct Pumping System with vertical tank	Combined Pumping System
1	BOGOTÁ	878	>5m²	SI	6	80	2,6	2,6	2,65	2,5
2	MEDELLÍN	1765	>5m²	SI	6	80	2,8	2,75	2,8	2,9
3	CALI	1445	>5m²	SI	6	80	2,8	2,75	2,8	2,9
4	BARRANQUILLA	742	>5m²	SI	6	80	2,6	2,6	2,65	2,5
5	BUCARAMANGA	1314	>5m²	SI	6	80	2,8	2,75	2,8	2,9

Table 3. Scenarios Results

Testing results Summary are shown in Table 3, extended results can be found in appendices. Same scenario was evaluated for each city: garden area bigger than 5 square meters, loft existence, socioeconomic level 6, and 80 square meters of impermeable roof. The Matrix successfully evaluate each scenario, suggesting the best alternative according to initial parameters. Despite have established same conditions for all cities, results are different. In this case, multi-year average precipitation on cases 1 and 3 is below 1000 mm, so that runoff volume does not represent enough storage to propose a combined system.

Selected system, corresponds to the highest score after the evaluation. However, some scenarios presented similar scores, allowing the matrix to recommend any of the recycling systems.

Even though weights selection were proposed by the authors, different scenarios results been adjusting to design requirement and restrictions, especially for low socioeconomic level, in which combined system is not profitable. Calibration process was necessary to set correct parameter weights, that rebound on accurate evaluations.

Although multi-criteria matrix was performed for five cities across Colombia´s geography, matrix could be expanding to every region if precipitation data is obtained from IDEAM. The foregoing will allow to be a solution for the supply of rural areas, and with low access to the water resource.

CONCLUSIONS

The application of multi-criteria matrix is effective in the selection of a suitable rainwater reuse system based on the results from the modeled scenarios and represents a useful tool to facilitate decision-making processes for designers and administrative planning entities in countries like Colombia, where a lack of politics around rainwater recycling is evidenced.

Rainwater recycling has a big potential in tropical countries like Colombia, because os hydrological conditions and precipitation availability along the entire year. This study analyzed cities in five different states, showing that rainwater recycling is profitable practice in Colombia.

Multi-criteria matrix methodology, allowed the interaction of five parameters among four rainwater recycling systems proposed, according to each system requirement. Multi- criteria matrix results were consistent due to parameter weight calibration process. Despite the assignment of weights were subjectivity, the methodology allows to modify and incorporate rules that led made a successful calibrating.

Future research aims to include hydro-climatological variables under the effects of global phenomena such as El Niño-Oscillation of the South, (ENSO).

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Appendices

CASE	CITY	MULTI-YEAR AVERAGE PRECIPITATION (mm)	GARDEN AREA (m^2)	LOFT EXISTENCE	SOCIOECONOMICAL LEVEL	ROOF AREA (m^2)	Gravity System	Direct Pumping System with underground tank	Direct Pumping System with vertical tank	Combined Pumping System
1	BOGOTÁ	878	No Garden Area	NO	6	50	1,8	1,8	1,85	1,9
2	BOGOTÁ	878	No Garden Area	NO	6	50	1,8	1,8	1,85	1,9
3	BOGOTÁ	878	$<5m^2$	NO	5	101	2,05	2,35	2,25	2,25
4	BOGOTÁ	878	$>5m^2$	NO	2	101	1,7	2,25	1,95	2,1
5	BOGOTÁ	878	$>5m^2$	NO	6	150	2,1	2,65	2,45	2,5
6	BOGOTÁ	878	$<5m^2$	NO	5	150	2,05	2,35	2,25	2,25
7	BOGOTÁ	878	No Garden Area	YES	2	100	2,3	1,85	1,95	1,7
8	BOGOTÁ	878	No Garden Area	YES	3	100	2,5	2,05	2,2	1,9
9	BOGOTÁ	878	$>5m^2$	NO	2	60	1,5	2	1,75	2
10	BOGOTÁ	878	$>5m^2$	YES	5	120	2,8	2,85	2,85	2,6

CASE	CITY	MULTI-YEAR AVERAGE PRECIPITATION (mm)	GARDEN AREA (m^2)	LOFT EXISTENCE	SOCIOECONOMICAL LEVEL	ROOF AREA (m^2)	Gravity System	Direct Pumping System with underground tank	Direct Pumping System with vertical tank	Combined Pumping System
11	MEDELLÍN	1765	No Garden Area	NO	1	50	1,6	1,55	1,5	1,9
12	MEDELLÍN	1765	No Garden Area	NO	5	50	2	1,95	2	2,3
13	MEDELLÍN	1765	$<5m^2$	NO	5	101	2,25	2,5	2,4	2,65
14	MEDELLÍN	1765	$>5m^2$	NO	2	101	1,9	2,4	2,1	2,5
15	MEDELLÍN	1765	$>5m^2$	NO	6	100	2,3	2,8	2,6	2,9
16	MEDELLÍN	1765	$<5m^2$	NO	5	100	2,25	2,5	2,4	2,65
17	MEDELLÍN	1765	No Garden Area	YES	2	100	2,5	2	2,1	2,1
18	MEDELLÍN	1765	No Garden Area	YES	1	100	2,5	2	2,1	2,1
19	MEDELLÍN	1765	$>5m^2$	NO	2	60	1,7	2,15	1,9	2,4
20	MEDELLÍN	1765	$>5m^2$	YES	5	120	3	3	3	3

CASE	CITY	MULTI-YEAR AVERAGE PRECIPITATION (mm)	GARDEN AREA (m^2)	LOFT EXISTENCE	SOCIOECONOMICAL LEVEL	ROOF AREA (m^2)	Gravity System	Direct Pumping System with underground tank	Direct Pumping System with vertical tank	Combined Pumping System
21	CALI	1445	No Garden Area	NO	1	50	1,6	1,55	1,5	1,9
22	CALI	1445	No Garden Area	NO	6	50	2	1,95	2	2,3
23	CALI	1445	$<5m^2$	NO	5	101	2,25	2,5	2,4	2,65
24	CALI	1445	$>5m^2$	NO	2	101	1,9	2,4	2,1	2,5
25	CALI	1445	$>5m^2$	NO	6	100	2,3	2,8	2,6	2,9
26	CALI	1445	$<5m^2$	NO	5	100	2,25	2,5	2,4	2,65
27	CALI	1445	No Garden Area	YES	2	100	2,5	2	2,1	2,1
28	CALI	1445	No Garden Area	YES	3	100	2,7	2,2	2,35	2,3
29	CALI	1445	$>5m^2$	NO	2	60	1,7	2,15	1,9	2,4
30	CALI	1445	$>5m^2$	YES	5	120	3	3	3	3

CASE	CITY	MULTI-YEAR AVERAGE PRECIPITATION (mm)	GARDEN AREA (m^2)	LOFT EXISTENCE	SOCIOECONOMICAL LEVEL	ROOF AREA (m^2)	Gravity System	Direct Pumping System with underground tank	Direct Pumping System with vertical tank	Combined Pumping System
31	BARRANQUILLA	742	No Garden Area	NO	1	50	1,4	1,4	1,35	1,5
32	BARRANQUILLA	742	No Garden Area	NO	6	50	1,8	1,8	1,85	1,9
33	BARRANQUILLA	742	$<5m^2$	NO	5	101	2,05	2,35	2,25	2,25
34	BARRANQUILLA	742	$>5m^2$	NO	2	101	1,7	2,25	1,95	2,1
35	BARRANQUILLA	742	$>5m^2$	NO	6	100	2,1	2,65	2,45	2,5
36	BARRANQUILLA	742	$<5m^2$	NO	5	100	2,05	2,35	2,25	2,25
37	BARRANQUILLA	742	No Garden Area	YES	2	100	2,3	1,85	1,95	1,7
38	BARRANQUILLA	742	No Garden Area	YES	3	100	2,5	2,05	2,2	1,9
39	BARRANQUILLA	742	$>5m^2$	NO	2	60	1,5	2	1,75	2
40	BARRANQUILLA	742	$>5m^2$	YES	5	120	2,8	2,85	2,85	2,6

CASE	CITY	MULTI-YEAR AVERAGE PRECIPITATION (mm)	GARDEN AREA (m²)	LOFT EXISTENCE	SOCIOECONOMICAL LEVEL	ROOF AREA (m²)	Gravity System	Direct Pumping System with underground tank	Direct Pumping System with vertical tank	Combined Pumping System
41	BUCARAMANGA	1314	No Garden Area	NO	1	50	1,6	1,55	1,5	1,9
42	BUCARAMANGA	1314	No Garden Area	NO	6	50	2	1,95	2	2,3
43	BUCARAMANGA	1314	<5m²	NO	5	101	2,25	2,5	2,4	2,65
44	BUCARAMANGA	1314	>5m²	NO	2	101	1,9	2,4	2,1	2,5
45	BUCARAMANGA	1314	>5m²	NO	6	100	2,3	2,8	2,6	2,9
46	BUCARAMANGA	1314	<5m²	NO	5	100	2,25	2,5	2,4	2,65
47	BUCARAMANGA	1314	No Garden Area	YES	2	100	2,5	2	2,1	2,1
48	BUCARAMANGA	1314	No Garden Area	YES	3	100	2,7	2,2	2,35	2,3
49	BUCARAMANGA	1314	>5m²	NO	2	60	1,7	2,15	1,9	2,4
50	BUCARAMANGA	1314	>5m²	YES	5	200	3	3	3	3