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Analysis and evaluation of proposals for rainwater harvesting systems for non-consumptive use in the city of Cuenca, Ecuador

María Paz González Durán[1*], *Federico* Córdova-González[1] and *Carlos Romo* Zamudio[1]

[1]Catholic University of Cuenca,Av. Américas y Humbolt, CP. 010101, Cuenca, Ecuador

Abstract. Due to the current population increase, the demand for the use of natural resources is also increasing exponentially, one of them is drinking water, this resource is one of the vital elements for human beings and has become the most exploited and specifically underutilized in residential buildings. Currently, this vital element has been used in cleaning activities, irrigation of plants and other non-consumptive activities. The World Health Organization recommends that water consumption should be 100 liters/inhabitant/day to consider a sustainable society; however, in the city of Cuenca- Ecuador, consumption doubles the recommended limit. Studies show that this consumption can be reduced with the application of bioclimatic strategies, one of which is rainwater harvesting. Therefore, this research focuses on the analysis and proposal for rainwater harvesting to solve the underuse of potable water in residential buildings for non-consumptive use (laundry, garden irrigation, house cleaning and toilet flushing). Thus, for rainwater harvesting for domestic purposes, the roof surface is used, and this model is known as SCAPT. The research methodology is of an experimental type in that collection strategies and systems are proposed, analyzed, and evaluated. With these rainwater harvesting systems, more than 55 litres/inhab/day can be incorporated into the dwelling, thus contributing to the reduction and control of drinking water in residential buildings.

1 Introduction

Currently, construction has begun to give more attention and importance to aspects of sustainability, and it is that the buildings today choose to incorporate various and better engineering practices that minimize the impacts on the environment, this is evident in better processes during the construction phases, Therefore, the need for efficient water management and use is highlighted, with the purpose of using it in smaller quantities when it comes from conventional sources for supply and can opt for the use of natural sources such as water from rain, which reduces the cost of supply as well as its transportation.

Even large buildings already incorporate rainwater harvesting systems to be used for household cleaning, washing or irrigation activities. Such buildings have an added value because they have considerably reduced the consumption of drinking water supplied by

* Corresponding author: mpgonzalezd43@est.ucacue.edu.ec

municipal agencies or rural boards, and they are also characterized by being environmentally sustainable [1].

Thus, in countries such as Colombia, rainwater harvesting systems have been implemented with the aim of minimizing the use of water resources in many regions, not only because of water pollution, but also because of the degradation of watersheds, as in the case of the Bogotá River, which is polluted and degraded. Colombia, due to its geographical location, has favourable conditions to implement rainwater harvesting systems as it is located on the equatorial line, which could collect up to 5,000 litres per m^2 per year. However, there are not many projects implemented in the urban context. In Mexico, on the other hand, projects focused on rainwater harvesting have been presented as an option to face the problem of water supply in rural areas, as well as aquifer exploitation. It is known that water extraction amounts to 60% of the total volume of aquifers for consumptive use, being the rural population the most dependent on them, especially in arid areas [2].

Nicaragua also has important natural water sources; however, it has seen the need to capture rainwater for different uses, taking advantage of this possibility in areas of high and moderate rainfall ranging from 80 mm in dry areas to 5,000 mm in wet areas. Rainwater is used for agricultural and livestock purposes. In countries such as France, rainwater harvesting is being implemented as a common alternative for water supply. At present, 15% of the inhabitants of this country have a rainwater harvesting system; for this reason, this issue is already being considered in new legislation, as well as the development of initiatives by the government to encourage these types of technologies [3].

In Ecuador, construction with rainwater harvesting systems is not new; however, it has not been popularized, although it has gradually become more relevant due to the potential it has because of the climatic conditions. For example, in the city of Esmeraldas, a pilot system was implemented in 34 educational institutions to collect rainwater when there was a shortage of drinking water. The project focused on collecting rainwater from the roofs of the school buildings for use in toilets and cleaning the facilities, storing it in existing cisterns and other underground tanks. The system has a useful life of up to 25 years and its economic viability could be verified, as well as an annual water collection of 77.05 m3, implying an annual water saving of approximately 45.6 m3 per educational institution [4].

There is also a system implemented in Pichincha, Quito canton, Tumbaco parish, where a rainwater collection project was developed in elevated tanks (30,000 litres) through the roofs of residences for domestic use. In addition to subway tanks with a capacity of 50,000 to 500,000 litres, the rainwater collected by runoff was used for livestock, agricultural and irrigation activities [5]. On the other hand, in the province of Loja, especially in rural areas, rainwater storage systems have been observed by means of pools located in the highlands, this for agricultural purposes, also allowing the conservation of soil moisture in the summer season, such reservoirs are usually approximately 20 m in diameter by 2 m deep [6].

In this context, it is possible to indicate that there is water stress resulting from population growth, the high demand for water currently represents a social and economic problem derived from the environment on a global, regional and local scale [7], which has caused drinking water, a vital element for human beings, to become the most exploited and underutilized, either due to a flaw in the management of water collection and distribution infrastructure, bad consumption habits [8]; and the lack of culture regarding the reuse and exploitation of the resource. Therefore, the lack of recognition of its value is the main cause of its misuse and waste [9].

In view of the above, the main objective of this research is to propose strategies for the collection and reuse of rainwater in residential buildings through documentary research to control the use of drinking water in these buildings. In addition, the specific objectives are to detail the rainwater harvesting systems that are best adapted to residential buildings to avoid wasting drinking water; to establish rainwater harvesting strategies for the different non-consumptive uses of a residential dwelling; and to analyze the non-consumptive uses in which the water collected by rain could be reused and taken advantage of by means of the SCAPT model. Thus, for the purposes explained, the SCAPT model will be used (rainwater harvesting system on roofs) in such a way that rainwater will be intercepted on the roof of the building, subsequently collected and stored in tanks for later non-consumptive uses.

1.1 Overview of rainwater harvesting systems on rooftops

In rainwater harvesting systems on roofs it is necessary to take into account certain elements that are of great relevance such as storage tanks, as well as the type of building, catchment area and even the uses of the water, in order to size the volume to be stored. In this regard, it is mentioned that a roof rainwater harvesting system is composed of the catchment area corresponding to the roof of the building, which varies according to the materials and degree of inclination, since the runoff of the liquid depends on this. It should also be mentioned that the quality of the water will depend on the type of roof or ceiling of the house, since some materials may contain toxic elements and even foreign agents that react with rainwater [10].

In this regard, in the city of Cuenca, the materials commonly used include galvanized metal roofs identified as zinc, which, according to recommendations, should be covered with food-grade paint to reduce the risk of releasing toxic substances when in contact with rainwater. In addition, there are roof tiles, made of baked clay, as well as concrete or fiber cement sheets that do not have toxic conditions when in contact with water. However, care should be taken not to work with materials whose components are lead or mercury or that contain asbestos, asphalt and even pesticide cures in the case of wood [11]. Regarding the degree of inclination, the optimum reference is 20% so that rainwater drains into the collection system. At this point it is also important to consider the level of runoff efficiency of the roofing material, so that different materials have different coefficients, for example, galvanized metal has a runoff coefficient of 0.85, while concrete 0.80, plastic 0.73, tile 0.66, canvas 0.55 and straw 0.20 [12].

On the other hand, it is necessary to consider the hydrological conditions in the region where the project will be carried out, since these are variable according to the seasons of the year, with long and intense periods of rain, others rather moderate and also dry periods of low or scarce rainfall. In the case of Cuenca, rainfall, in terms of quantity, quality and regularity, is adequate for rainwater harvesting [13].

In this regard, the Ministry of Environment and Sustainable Development in Ecuador, through a technical document, which establishes guidelines for rainwater harvesting, suggests that it is also necessary to evaluate the water demand in the home, i.e. the amount consumed per person to size the total consumption. Consumption can be classified according to use, number of users, geographical area where the house is located, among other aspects, in this way it will be possible to identify the use of rainwater to cover the needs of irrigation of gardens or crops, sanitary discharge, cleaning of areas in the home such as floors and patios, use in washing machines, etc. This information is useful for calculating the size of the storage tank, which should also meet special conditions according to the volume to be stored [14].

The storage tank should be considered as an important element in the rainwater harvesting system, since it will contain the collected liquid until it is used. Thus, the tanks can be located in areas outside the house, either in high or low areas, and there is also the possibility of burying them; these conditions will depend on technical aspects of the project, as well as on the budget. In this sense, tank materials vary and can be made of polyethylene, steel, concrete, fiber cement, among other materials [15].

In addition to this, complementary works are considered because sometimes these are required to maintain or improve the system, including the need for a settling tank, energy trigger, pumping equipment, drinking water treatment system, among others. Maintenance is essential to ensure that the catchment area is free of weeds or other elements that impede runoff, as well as the channel openings. The storage tank also requires maintenance to prevent the growth of algae or contaminating microorganisms [13].

1.2 Stages of the rainwater harvesting system in roofs

The SCAPT takes advantage of rainwater by capturing it and diverting it through a system of channels and pipes that lead it to a storage tank for later use. This system has been considered the most practical and economical to develop in relation to other alternatives. It requires minimal care that involves paying attention to the first rain that falls as it may wash away materials or debris on the roof (a procedure known as first water separation or discharge), in addition to keeping the water channels and filters clean. The SCAPT also implies water savings and economic benefits. It is characterized by 4 stages: catchment, collection/conduction, first rain separation and storage [16].

The first or catchment stage takes place on the roof area, since it is the roof that catches the rainwater and filters it through its surface thanks to its slope and depending on its material, since there are materials that allow more water runoff than others. The water that flows down the roof reaches the gutter area at the end of the roof, where the liquid circulates through pipes that direct it through the collection system, which can be a filter such as the interceptor (first rainwater filter) and finally pass to the storage tank [17].

At the storage stage, the rainwater has passed through the collection system until it reaches the storage tank, so it will have circulated through previous filtration systems to isolate solids. In the tank the water can be further treated if required with chlorine, for example, or other filtering systems before use. This will depend on the uses of the rainwater, whether they are consumptive or non-consumptive. In addition, the tank can be connected to distribution networks according to the uses such as garden irrigation, home network, washing machine, toilets and shower, or simply have its own tap for direct supply at the time that users require it [18].

At this point it is necessary to establish that there are different ways of configuring the rainwater harvesting system for roofs, which can be simple and low cost or complex and with a high value, this will depend, fundamentally, on the conditions of the project, the building and the use of water. In the case of simple systems, rainwater is generally transferred to the lower areas of the house for storage and direct use, and in the case of complex systems, they are proposed with the intention of capturing, treating, storing and distributing rainwater, so that it can be used to meet the various needs of individuals in a house, so they generally have an interceptor filter, in addition to other filters to disinfect the water of microorganisms and improve its quality, and other complementary systems are also usually incorporated to allow adequate supply, pumping and distribution [19].

It is also feasible to mention that, as part of the considerations of sustainable architecture, technical rooms, storage tanks and piping ducts should be taken into account. These spaces, due to the fact that they are not commercialized, are complicated to work with, since in elements such as the storage tank, the work demands a large surface area and sometimes even requires specific structures that have an impact on the value of the project [20]. Therefore, a tank design must be properly adjusted, trying to avoid oversizing from the economic perspective and consequently with the efficient use of water, finally what is sought is the use of rainwater in terms of cost by saving and optimizing the resource.

Thus, the rainwater storage tank fulfils the following functions: contain or store rainwater, providing a reserve of liquid to the house in seasons or periods in which there may be interruptions or irregularities with rainfall; level the stored water for its treatment for consumption purposes (potabilization) or for cleaning or washing; reduce the discharge of rainwater into the building's drains when there is heavy rainfall. In addition to the above, reference is made to the economic and technical feasibility of the projects, which will vary according to the rainfall conditions of the area where rainwater harvesting is carried out and also the use of rainwater.

1.3 Feasibility studies for rainwater harvesting system on rooftops

There are different studies and proposals put into practice on rainwater harvesting systems through roofs in different countries; however, they are not always followed up properly, so it is not possible to know their progress and behaviour over time in all cases. Nevertheless, it is possible to obtain records in the initial stages that serve as a guide for another research.

Thus, for example, the proposal for the design of a system for the collection of rainwater for use in crop irrigation for a farm in Boyacá, Colombia is presented, in which comparisons were made between different rainwater collection processes based on the requirements presented by the farm, thus evaluating the use of a modular outdoor tank, a buried tank and a system for collecting water through a control process. The comparison, based on the conditions of the area, the uses of water, the needs of the farm and other aspects such as rainfall conditions, allowed determining that the outdoor tank was the best option, and it was also determined that according to the average rainfall in the area, the adaptation of polyethylene tiles was required to obtain the required amount of water, calculated at 6,450 litres per month [21].

An analysis of urban flooding in the northern area of Chapinero is also recorded in Bogota, replacing the roofs of houses with green roofs by means of digital modelling with different substrates and plants. The study found that sawdust was 46% more efficient than other materials, and the Sedum plant was more resistant to frequent rains. When comparing the relationship between the number of green roofs incorporated and flooding levels, there was an 88.9% decrease in flooding of the wells where rainwater drains. Thus, green technology contributes to the reduction of flood risks in the urban sector and allows the creation of conditions for the integrated management of water resources [22]. Another rainwater harvesting project for irrigation of a hydroponic crop was carried out in Boza, Bogota. The roof for rainwater harvesting was made of plastic, covering an area of 7.5 m by 3 m, with an inclination of 10°, the collection was done through gutters that directed the water towards the interceptor with a volume of 15 litres, a system of sand and gravel filters with a height of 0.43 m and a diameter of 0.0762 m was also installed. This system is connected to another one that is composed of 4 columns of tubes with a capacity of 3 plants each, the water is distributed to these by means of a pump with automatic ignition with timer. The vegetables for hydroponics were lettuce, spinach, mint, oregano, parsley, tomato, celery, basil and garlic. It was demonstrated that the project was viable in that it allowed the development of the plants, but it was also verified that the roof material supported the weight of the system and did not modify the quality of the rainwater [23].

In Ecuador, a project was identified that proposes a system to take advantage of rainwater considering architectural aspects of the buildings, as well as hydro-sanitary aspects since the use of rainwater will be for the discharge of sanitary devices, in addition to the pattern of water use, unit consumption, factors of use and finally determining the volume of consumption. Thus, it was identified that the monthly water consumption was 56 m^3 for urinals, toilets and other uses such as outdoor cleaning. The surface area for collection by means of a roof corresponded to 138 m^2, but an infiltration area of 1,500 m^2 was also taken into account. It was calculated that the volume of the reservoir would be 15 m^3 allowing 88.4% of the rainwater to be used, guaranteeing the availability of liquid for non-consumptive use in the building. The project resulted in water efficiency, resulting in a 31% reduction in potable water consumption, which in economic terms is equivalent to a 45% saving, and also reduced the risk of flooding [24].

There is also a study that proposes a system for using rainwater to supply a production plant in Cota, Colombia. The water was used to supply cooling towers and reduce potable water consumption. The study involved the analysis of meteorological and structural aspects of the plant and the design of the rainwater collection system. The daily water requirement for the estimated purposes was 5 m^3 and the plant has a roof area of 3,300 m^2 equivalent to only 50% of the warehouses. The system contemplated the collection of water through the roofs and through PVC pipes that lead the rainwater to the drains, consisting of three downspouts with a diameter of 6" and 10 m long. The water is conveyed to a first water interceptor tank with a capacity of up to 6,000 litres, after which the water is transferred to a storage tank with a capacity of 10,000 litres. The project resulted in annual savings of 12%, i.e. 40% of the total water consumed in the winery [25].

2 Methodology

The applied-experimental line of research was used to increase the understanding of rainwater harvesting using the SCAPT model and to evaluate the behaviour of the proposed harvesting systems. The experimental design also aims to draw conclusions about a research problem based on a given conceptual framework. Considering these criteria, the study will be divided into four stages: Stage 1: In the present stage, a bibliographic review of technical aspects and proposed strategies for rainwater harvesting was carried out in order to apply such references in the present project and establish comparisons with the proposed strategies, which comprise a rainwater harvesting system on a fiber cement roof and another on a tile roof, both applied with three levels of filtering. Stage 2: We proceed with the application of the experiment. Based on the information reviewed, a SCAPT (roof rainwater harvesting) strategy was applied at scale to simulate the system on fiber cement and tile roofs. Stage 3: In this phase we proceed with the analysis and evaluation of 2 cases of rainwater harvesting from roofs already developed in the city of Cuenca and their update according to current rainfall conditions.

2.1 Equipment and materials for the experiment

For the SCAPT model scale experiment, the following materials have been specified: rainwater catchment area (roof): fiber cement sheet and tiles, gutters, downspouts, water storage tanks and accessories, filters, rainwater. The catchment area comprises a 0.75 m x 0.50 cm fiber cement sheet and a tile roof with the same dimensions. The runoff efficiency in the former was 0.80 and in the latter 0.66. The gutter used in the experiments was improvised with PVC material (adapted pipe) that was placed at the edge of the roofs on the lower part to receive the water collected on the roof. The downspout considered was made of PVC, to which PVC pipe and elbows were adapted to simulate the conduit through which the water circulates. A 5-gallon plastic bucket (18.9271 litres) was used as a storage tank. The filters in the collection system for the experiments consisted of a mesh placed in the channel and the second was the system for separating the first rainwater or interceptor filter. Finally, the rainwater was previously collected in the amount of 10 litres and was not subjected to filtering or purification.

2.2 Experimental procedure

The experiments begin with the assembly of the structures, starting with the adaptation of the roofs (fiber cement sheet and tile) with an inclination of 20°, as well as the channel and the mesh along them to prevent the passage of any type of large material. The second filter, known as the interceptor, is then installed upstream of the water storage tank. Once the structure was installed, the contents were poured onto the roof to simulate the water falling during a rainfall. The amount of water used was 10 liters.

Fig. 1. Left: asbestos cement roof; right: tile roof.

In the process it is observed that the water falls through the roof to the channel, in which the material such as leaves and branches is filtered, the water continues its journey and circulates to the downspout, through which it reaches the interceptor filter which worked through a filling system with the first water that falls through the channel and the downspout, Then the filter receives the dirty water until it fills its catchment level and is covered, so the next water that circulates through the catchment system passes directly to the storage tank, thus filtering the first rainwater received, finally the water is directed to the storage tank (See Fig. 1).

3 Results

The results of the experiments showed that the total catchment area of both cases was 0.375 m^2. In the case of the use of fiber cement, the water retention in the interceptor filter was 1.35 litres, so the effective rainwater harvesting of the system was 8.48 litres, that is, 85% of the total liquid received by the roof. In the case of the experiment with tiles, the interceptor filter also retained 1.35 litres corresponding to the first rainwater, allowing 7.73 litres of liquid to pass through for storage in the tank, so it is understood that 77% of the effective capture is achieved with the tile roof.

Subsequently, comparative analyses of two cases already executed are considered, the first one, identified as "A" in which a rainwater collection system was designed for a house with a fiber cement roof with a catchment area of 180 m^2 in which the consumption of 5 people was to be supplied, with an average of 200 litres per day for each one [26].

The filtration system designed corresponded to the gutter mesh, the interceptor of the first rainwater and a last filter placed in the storage tank consisting of a 0.35 mm mesh. In case "B", a rainwater collection system was calculated and designed for a house with a tile roof with a catchment area of 160 m^2 and a family of 4 members, with a daily consumption of 197 litres. For this case, the filtration systems were incorporated with mesh in the channel, an interceptor for the first rainwater and a mesh in the storage tank, the thickness of which is not specified, but it contains carbon fibers [27].

In relation to the uses, in Case A the largest amount is for sanitary consumption with 29%, washing clothes, patios, car and garden irrigation represents 24%, the shower registers 20%. These correspond to non-consumptive uses equivalent to 73% of total potable water consumption. In Case B, 30% was recorded for washing clothes, patios, carts and garden irrigation; 25% for sanitary flushing and 19% for showering, equivalent to 74% of total potable water consumption in non-consumptive uses.

Therefore, the estimated demand for 5 people with a consumption of 200 L per person was 365 m^3 per year (See Table 1). As for the collection potential, according to INAHMI meteorological records in 2011 in Cuenca, it was identified that rainwater collection could be 259.48 m^3 per year, covering a demand of approximately 222.65 m^3 (See Table 1).

Table 1. Water demand and collection potential in Case A.

Water demand					Collection potential 2021			
Month	**Day of the month**	**LP/DxDmes (200 L)**	**LP/DxPxDmes Demand (L)**	**Volume m^3**	**R mm of rain**	**x A (160 m^2) L**	**x CR (0.80) L**	**/1000 m^3**
Jan	31	6200	31000	31	271.1	43376	34700.8	34.70
Feb	28	5600	28000	28	492.7	78832	63065.6	63.07
Mar	31	6200	31000	31	508.4	81344	65075.2	65.08
Apr	30	6000	30000	30	306.3	49008	39206.4	39.21
May	31	6200	31000	31	154.3	24688	19750.4	19.75
Jun	30	6000	30000	30	44.4	7104	5683.2	5.68
Jul	31	6200	31000	31	19.5	3120	2496	2.50
Aug	31	6200	31000	31	15.5	2480	1984	1.98
Sep	30	6000	30000	30	23.7	3792	3033.6	3.03
Oct	31	6200	31000	31	25.9	4144	3315.2	3.32
Nov	30	6000	30000	30	63.1	10096	8076.8	8.08
Dec	31	6200	31000	31	102.3	16368	13094.4	13.09
Annual	**365**	**73000**	**365000**	**365**	**2027.2**	**324352**	**259481.6**	**259.48**

Proceeding with the update of the collection potential in the year 2023, with the Weather Atlas average data of rainfall conditions, it was evidenced a catchment of up to 151.17 m^3 in the year (See Table 2). In other words, compared to 2011, the amount of rainwater captured decreases by 60%.

Table 2. Update of collection potential in the year 2023, Case A.

Month	R mm of rain	x A (160 m^2) L	x CR (0,80) L	/1000 m^3
Jan	127	20320	16256	16.26
Feb	133	21280	17024	17.02
Mar	157	25120	20096	20.10
Apr	128	20480	16384	16.38
May	96	15360	12288	12.29
Jun	50	8000	6400	6.40
Jul	52	8320	6656	6.66
Aug	35	5600	4480	4.48
Sep	43	6880	5504	5.50
Oct	113	18080	14464	14.46
Nov	129	20640	16512	16.51
Dec	118	18880	15104	15.10
Annual	**1181**	**188960**	**151168**	**151.17**

Referring to Case B, for a 4-person household with an average daily consumption by each of 197L, characterized by a tile roof and a catchment area of 140 m^2, it was obtained that the annual water demand was 287.62 m^3 (See Table 3). In addition, the rainwater collection potential was estimated to be 88.98 m^3 according to the 2019 rainfall conditions recorded by INAHMI. Then the amount of rainwater collected, in relation to the water demanded in the dwelling, would cover 31% of the potable water consumption. Updating the rainfall conditions to the year 2023, it was obtained that rainwater collection would be 109.12 m^3, i.e. 20.12 m^3 more than in 2019. This result is favourable for housing and the coverage of its water demands for non-consumptive uses (See Table 4). In 2019, due to rainfall conditions, 31% of the water demand could be covered and by 2023, 38% could be covered. However, in this case, it was evident that the tile roof accumulated rainwater pollutants such as dry leaves and soil, and in some areas, there were even roots. This indicated the need for cleaning and major maintenance prior to each rain cycle.

Table 3. Water demand and collection potential in Case B.

Water demand					**Collection potential 2019**			
Month	**Day of the month**	**LP/DxDmes (197 L)**	**LP/DxPxDmes Demand (L)**	**Volume m^3**	**R mm of rain**	**x A (140 m^2) L**	**x CR (0,66) L**	**/1000 m^3**
Feb	28	5516	22064	22.06	59.2	8288	5470.08	5.47
Mar	31	6107	24428	24.43	109.5	15330	10117.80	10.12
Apr	30	5910	23640	23.64	95.8	13412	8851.92	8.85
May	31	6107	24428	24.43	77.2	10808	7133.28	7.13
Jun	30	5910	23640	23.64	25.9	3626	2393.16	2.39
Jul	31	6107	24428	24.43	16.6	2324	1533.84	1.53
Aug	31	6107	24428	24.43	16.6	2324	1533.84	1.53
Sep	30	5910	23640	23.64	39.8	5572	3677.52	3.68
Oct	31	6107	24428	24.43	131.7	18438	12169.08	12.17
Nov	30	5910	23640	23.64	123.2	17248	11383.68	11.38
Dec	31	6107	24428	24.43	129.1	18074	11928.84	11.93
Annual	**365**	**71905**	**287620**	**287.62**	**963**	**134820**	**88981.2**	**88.98**

Table 4. Update of collection potential in the year 2023, Case B.

Month	**R mm of rain**	**x A (160 m^2) L**	**x CR (0,80) L**	**/1000 m^3**
Jan	127	17780	11734.80	11.73
Feb	133	18620	12289.20	12.29
Mar	157	21980	14506.80	14.51
Apr	128	17920	11827.20	11.83
May	96	13440	8870.40	8.87
Jun	50	7000	4620.00	4.62
Jul	52	7280	4804.80	4.80
Aug	35	4900	3234.00	3.23
Sep	43	6020	3973.20	3.97
Oct	113	15820	10441.20	10.44
Nov	129	18060	11919.60	11.92
Dec	118	16520	10903.20	10.90
Annual	**1181**	**165340**	**109124.4**	**109.12**

4 Conclusions

In compliance with the general objective of proposing strategies for the collection and reuse of rainwater in residential buildings through documentary research to control the use of drinking water in these buildings, two proposals have been estimated. Thus, we have the use of tile and fiber cement in the roofs of houses, materials that are used in the city and that characterize it, especially the first one because it is a very important element in its architecture and throughout its history. Once the experiments were developed, it was possible to verify the effectiveness of the SCAPT model both for the case of fiber cement and tile surfaces.

In this sense, it was recorded that the filters applied are effective for the purposes explained in the theory and in the practice of the different projects executed. The mesh filter in the gutter allows the retention of large material such as leaves, branches and even any other element that can be dragged with the wind or rain, preventing the passage to the gutter and therefore to the downspouts, which favours so that these are not clogged and the system flows effectively. The mesh filter is effective in the case of the fiber cement roof as in the tile roof, the variation will depend only on the amount of material that can go down the roofs and the capacity of the mesh to filter them, however, this also contemplates other factors such as the thickness of the mesh, its installation, material, maintenance, area to be covered, among others. As for the second filter applied in the experiments, the interceptor, the system captures the first water that reaches it, allowing the liquid with the contaminating material such as soil to remain in the container, while allowing the less contaminated water to pass to the storage tank. It is worth mentioning that the amount of water retained in the interceptor is equivalent to its capacity, which is established considering variables such as the surface catchment potential, as well as rainfall conditions and system-specific aspects that are assessed during its design and technical approach.

In relation to the roof material, it was found that this favours the capture of more liquid in the presence of a similar amount of rainwater reception on its surfaces during the experiment. Thus, the fiber cement surface allows greater circulation of liquid, soil and other elements that the water can drag, while the tile accumulates material between the gutter and the roof, precisely because of its arrangement.

On the other hand, in order to detail the rainwater harvesting systems that are better adapted to residential buildings to avoid wasting drinking water, a theoretical and practical foundation has been carried out, showing the feasibility of implementing a SCAPT model. Thus, it has been demonstrated that the use of fiber cement sheets is more effective due to their runoff level, which allows for greater rainwater capture, and also implies less maintenance of the surface and presents fewer problems with materials dragged by rain and wind, as well as dust concentration or deterioration, since the tiles can even generate mould due to humidity. Even in the comparison of the two cases analyzed, it was possible to identify that the difference in the roofing material (fiber cement and tile) has a considerable impact on runoff, since rainwater collection is greater in the case of strategy A (fiber cement) compared to strategy B (tile). The tile roof concentrates more dirt on the surface and requires more cleaning than the fiber cement roof.

In coherence with the above and in attention to the establishment of rainwater harvesting strategies for the different non-consumptive uses of a residential dwelling, it is considered that for the SCAPT model, the strategic actions imply the use of roofs that allow a good runoff such as fiber cement, zinc, polycarbonate and even tile. It is precisely these materials that are used in the city of Cuenca in buildings. It is also possible to talk about collection strategies such as capture by filtration or runoff when there is ample land that can be used to capture the water that reaches the ground or by means of smaller scale basins; however, this requires another type of study. There is also the option of green roofs, which consists of the incorporation of roofs with water capture systems by filtration, but which also generate other benefits through the plants that can be planted and cultivated on them. This option does not yet have practical implementations at the national level, but it is already an alternative in different countries that could well be implemented in Ecuador.

Finally, considering the analysis of the non-consumptive uses in which the water collected from rainfall could be reused and taken advantage of through the SCAPT model, it is considered that the most common are the irrigation of plants or gardens and crops, sanitary discharge, washing or cleaning of spaces at home, even washing cars and clothes, but it has been possible to register, through research, diverse uses such as in the industrial field or for hydroponic crops, bathing domestic animals, among others. This shows that there is a great possibility to begin to become aware of water consumption, be it potable or from other sources, but water collection projects must be within the reach of the community and not only from an economic approach but also starting from communication, since citizens are unaware of these and their benefits. It is necessary to socialize them and demonstrate that their implementation is feasible in Cuenca because many of the houses have suitable structures for this, since they have incorporated gutters, downspouts, tile or fiber cement roofs, and even other materials that are also viable such as polycarbonate or galvanized steel, in addition to the rainfall conditions are favourable. While the implementation of filters can be adaptable with a previous technical study, as well as the location of the storage tank without affecting the harmony of the buildings.

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