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Rainwater Atmospheric Contamination And Its Incidence For Construction Projects Applicability

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Summary
This article shows the relation between atmospheric pollution and the quality of rainwater in urbanized centers, as well as the incidence on the behavior of construction materials such as concrete used in building construction. The study includes data collected at the monitoring stations located in the metropolitan area of Medellín, Colombia, which measures the presence of particulate matter $PM_{2.5}$ and PM_{10} ($\mu g/m^3$). Samples of drinking water and rainwater were also studied to determine, if there were important differences between them. Identifying aspects, such as pH, presence of sulfates (SO_{4-2}) and chlorides (Cl-). Additionally, parameters of international and national standards required for the manufacture of concrete mixtures were compared. The results obtained from measurements of air pollution, composition of rainwater and drinking water, resistances of concrete samples and savings of water consumption in buildings, allowed to conclude that there is a direct relationship between air quality and rain water. However, this is not an obstacle to an urban use of this resource in the construction industry, contributing to reduce pressure on water sources.

Key words: atmospheric pollution; rain water; sustainable construction; urban environment.

1. Introduction

Water stress is a common factor in a large percentage of the world's cities. In Latin America, specifically in Colombia, guaranteeing potable water for communities is getting progressively more complicated, due to treatment costs and growing demand for both, human consumption and the construction industry[1]. However, in much of the territory, the annual average rainfall is positive. Therefore, seeking to reduce the environmental impact on the urban ecosystem of the metropolitan area of the city of Medellin, which has a population of 3 731 447 inhabitants[2], the environmental variables of air quality and rainwater composition were analyzed, with the objective of correlating them and thus corroborating the possibility of using rainwater as a raw material for construction projects in activities such as rain water collection, washing of structures and making materials such as the concrete, among others.

Table 1. Average rain water in Medellín, Colombia. Source: IDEAM (2018).

Average rain water per bimester (mm)					
Jan-Feb	March-April	May-June	July-Aug	Sep-Oct	Nov-Dec
149	281	352	270	392	241

According to the table 1, the averages of precipitation in the studied region are worthy[3], considering an annual average[4] of 1 685 mm, is possible to infer that this fluid can be collected for use in activities that do not require drinking water. Nonetheless, this depends to a large extent on the air quality of the site[5], since during the first minutes of precipitation the water drags the particles that are suspended in the air, which can affect the viability of its use in processes that do not require treated water for human consumption, but must comply with required parameters of technical and environmental standards.

The study taked into account data from the network of meteorological monitoring stations installed in the metropolitan region of Medellín, which has 19 measuring points of $PM_{2.5}$ and PM_{10} particulate material, as shown in figures 1, 2 and 3.

Figure 1. Geographic location of Colombia. Source: SIATA (2018).

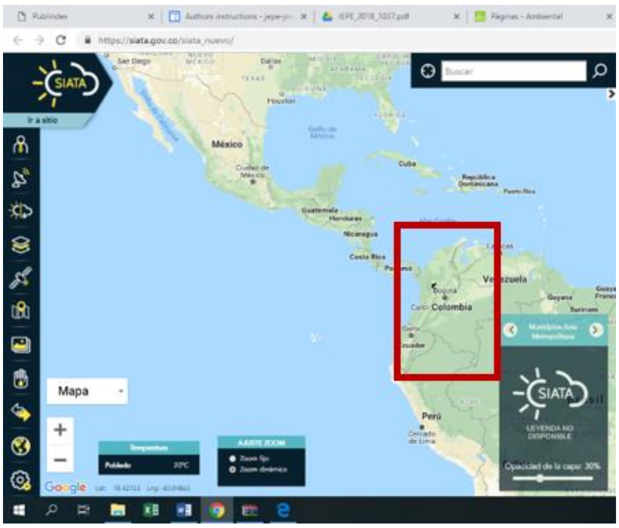


Figure 2. Metropolitan area of Medellín. Source: SIATA (2018).

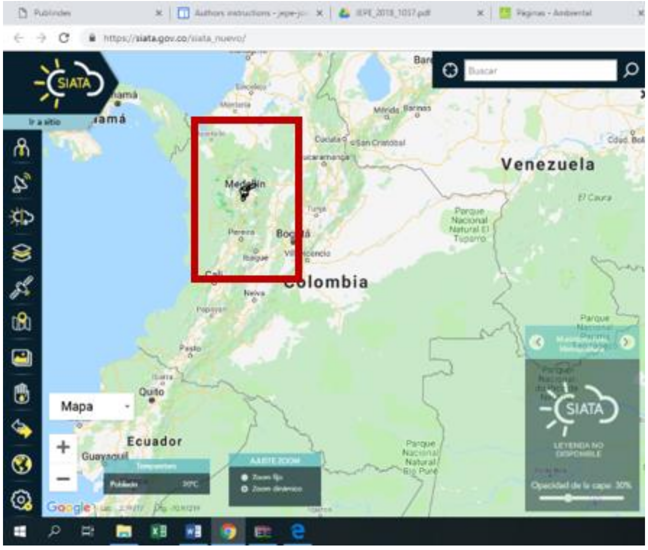
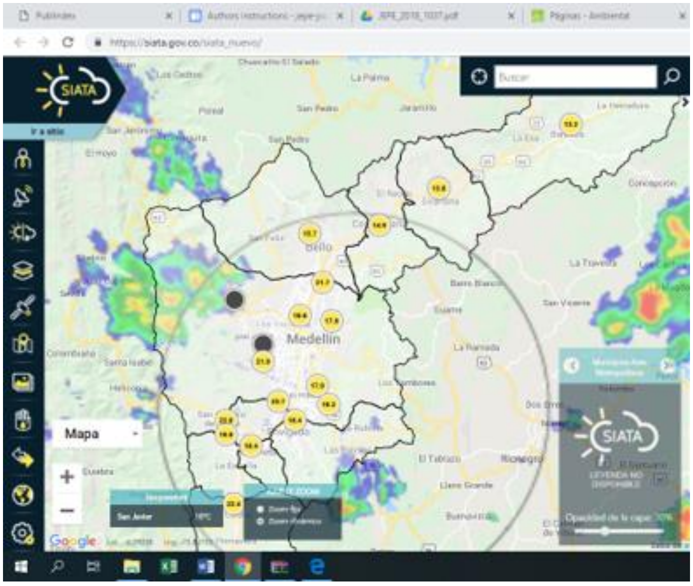


Figure 3. Location of air quality monitoring stations. Source: SIATA (2018).



With rain averages and the location of the monitoring stations identified, the experimental strategy was developed to determine the economic, technical and environmental feasibility of reusing rainwater in urban-scale construction processes.

2. Materials and Methods

The most critical monitoring point was identified and chosen in terms of particulate material; rainwater was collected from the critical point area; chemical analysis of the collected water was made and the results were compared according to the norm NTC 3459[6] or ASTM C1602[7]. In addition, a building under construction was identified in the area of influence of monitoring to use rainwater in construction processes and rainwater collection; cylindrical concrete samples were also prepared for ordinary resistances[8]. The rainwater samples were collected after the first five minutes of precipitation, thus eliminating as many contaminants as possible that may affect its subsequent application in the construction processes. In the case of construction work, a hotel was selected, in which a 500-liter capacity tank was installed, from which a flexible polyethylene pipe was supplied, through which water was used to wash steel reinforcements, irrigation of green areas and floor cleaning[9]. In the case of use in the preparation of concrete mixtures, an ordinary resistance mix between 21 MPa and 25 MPa of compressive strength was designed, therefore cylindrical samples were emptied and taken to a curing tank in humidity of 100 % and constant temperature between 23 °C and 26 °C, later they were failed in electronic press at different ages of curing (7, 14, 28 and 56 days).

3. Results and Discussion

The air quality data in the chosen station in the center of the metropolitan area of Medellín can be seen in table 2.

Table 2. Average and maximum allowable values per year. Source: AMAVA (2018).

Referencia	**NO_2 (µg/m^3)**	**PM 2.5 (µg/m^3)**	**PM 10 (µg/m^3)**
Monitoring station	20,76	20,54	56,90
Maximum allowed	200,00	25,00	50,00

Regarding water quality, the following result was obtained, see table 3:

Table 3. Chemical analysis of water. Source: AMVA (2018).

Sample	**pH**	**Turbidity (NTU)**
Rain water	6,34	2,27
Purified water	6,80	0,10

According to these results was observed that the atmospheric air of the reference point complies with two of the required parameters (NO_2 and $PM_{2.5}$), and that the parameter of PM_{10} slightly exceeds the limit of the standard. Consequently, is possible to affirm that, by collecting rainwater with the proposed methodology which excludes the water precipitation of the first five minutes, water can present an optimal composition for construction processes and materials[10]. According to the table 3, in terms of turbidity, the rainwater sample is discarded for direct human consumption, but when analyzing the pH parameter both rainwater and drinking water meet the parameters to be used in the construction materials such as concrete.

Additionally, while contrasting the water samples (drinking and rain) with the parameters required by the Colombian technical standard NTC 3459, as shown in table 4. Was observed that both drinking and rain water can be used in the manufacture of concretes, since the sulfates (SO_{4-2}) and chlorides (Cl-) are well below the maximum limit required by the standard. Then rainwater used during the construction processes of the hotel and in the manufacture of simple concrete cylindrical test pieces for resistances from 21 MPa to 25 MPa.

Table 4. Parameters NTC 3459. Source, C. (2014, 2018).

Parameter	**Rain Water (mg/L)**	**Purified Water (mg/L)**	**NTC 3459 (mg/L)**
Sulfates	5,00	12,00	1 000
Chlorides	16,30	19,50	1 000
Total solids	28,50	32,00	50 000
Dissolved solids	27,00	1,00	2 000
pH	5,10	6,80	≥ 5
Turbidity NTU	4,20	0,10	NA

Use of rainwater in construction processes

Photo 1. Storage tank. Source: Pineda, E. (2015).

Photo 2. Water reuse in construction processes, Hotel. Source: Pineda, E. (2015).

Photo 3. Water reuse for garden irrigation. Source: Pineda, E. (2015).

Photo 4. Hotel facade. Source: Bedoya, C. (2018).

By having rainwater characterized by laboratory, thus complying with the technical standards required in the country, a permanent strategy of rainwater and groundwater was implemented during the construction of the building, which represented savings of 60 % in the construction processes and cleaning of the project.

Use of rainwater in concrete production

In this case, the collected rainwater was used to prepare concrete samples, in order to analyze whether it affects positively or negatively the physical and mechanical characteristics of the material. Hence, 24 compression test tubes (F'c) were failed at ages 7, 14, 28 and 56 days of age, with an average of three test tubes per age for each sample[11].

Table 5. Compressive strength of concrete samples.

Age (Days)	F´c Purified Water (MPa)	F´c Rain Water (MPa)
7	22,06	23,76
14	24,70	24,05
28	27,74	27,51

56	28,75	29,18

Table 6. Rain water statistics.

Age (days)	**Media**	**Standard deviation**	**Coefficient of variation**
7	23,06	0,75	3,25%
14	24,05	0,18	0,74%
28	27,51	0,18	0,64%
56	29,18	0,94	3,21%

Table 7. Purified water statistics.

Age (days)	**Media**	**Standard deviation**	**Coefficient of variation**
7	22,76	0,09	0,39%
14	24,70	0,13	0,54%
28	27,74	0,10	0,38%
56	28,75	0,04	0,14%

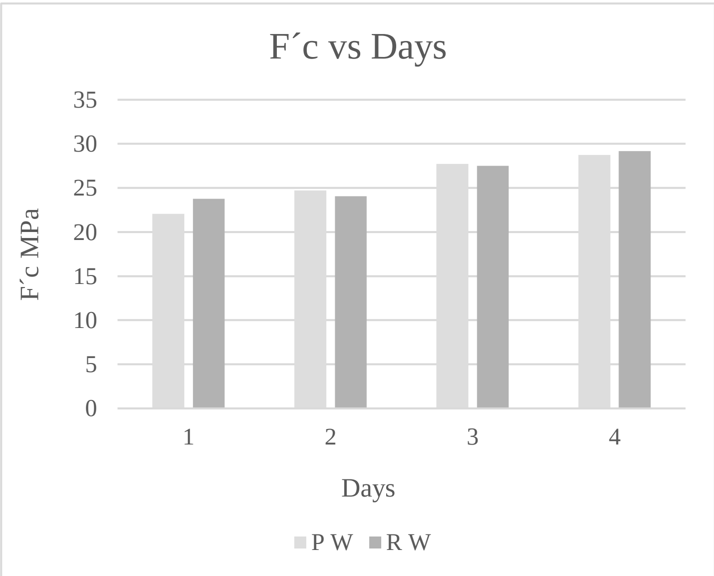


Figure 4. Comparison of the compressive strength of the samples.

Figure 4 shows that the behavior of the two mixtures is statistically equal, since their variation is minimal and both are maintained in the range of resistance required by technical standards, exceeding 25 MPa at 28 days of elaboration, and maintaining an upward stability at 56 days.

Conclusions

Atmospheric pollution does have an effect on the quality of rainwater, yet it was found that, discarding the precipitation of the first five minutes, the samples presented a composition with parameters were below the maximum limit of national and international standards[12], which allows its use in activities that do not require drinking water for human consumption.

The amount of precipitation in the metropolitan region of the studied territory is sufficient to implement rainwater use strategies in activities such as construction processes, cleaning and irrigation of gardens. Thus optimizing the consumption of water and reducing the pressure about water sources for human consumption. By presenting a saving in the water consumption of the city's aqueduct, the recharge of aquifers is favored and the costs of building construction are reduced, since rainwater becomes a resource of optimum performance and does not have cost.

The physical mechanical behavior of the cylindrical concrete samples made with rainwater was statistically optimal, in accordance with technical standards, which opens the possibility to design concrete manufacture processes based on a non-linear flow of consumption of resources and generation of waste. Concrete is one of the most consumed materials worldwide for the construction of buildings[13], requiring average resistances of 21 MPa and 25 MPa, and the amount of water necessary for the manufacture of a cubic meter of this material, varies between 180 and 210 liters (0.18 and 0.21 m^3)[14], consequently by using rainwater in areas with significant rainfall averages would have a positive impact on the urban ecosystem.

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