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Influence of Land Use on Runoff Quality in Bogotá, Colombia

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Abstract

It has been possible to determine how rainwater presents different pollutant loads, influenced mainly by soil usage and by different rain intensity, which generates environmental and ecological impacts. These impacts are strengthened in developing countries, where sustainable drainage systems are not available to reduce them and there are no policies that promote alternatives. This article evaluates the influence of land use on the concentrations of physical-chemical parameters in urban runoff. For this, an artificial rain was used at three points with different land uses (residential, industrial and vehicular parking) in the city of Bogotá. The results indicated that the industrial sector presented the highest concentrations of all parameters measured, mainly nitrates, nitrites, total suspended solids, COD and alkalinity. The residential area and the parking lot presented similar characteristics (in terms of the presence of vehicular traffic and vegetal species), however the biggest difference was found to be a higher concentration of COD in the residential area.

Keywords: Land use; urban runoff; pollution

1. INTRODUCTION

As societies develop and populations grow, the consequences include an increase in the extension of impervious areas and the growth of variety in land uses. This urbanization brings with it a great variety of hydrological and environmental problems which include: decreased infiltration of water through the soil (affecting the aquifers), greater runoff (that increases the risk of flooding), degradation of rainwater quality, increased erosion processes, decreased water retention capacity (by removal of plant cover) and changes in the physicochemical parameters of the receiving water bodies [1]–[3].

One of the most important impacts is the increase of pollutants in rainwater, associated with atmospheric and soil washing, as this generates significant problems to water bodies by diminishing water quality and altering their ecosystems [4]. This is why it is necessary for cities and their authorities to measure and quantify the concentrations of these pollutants, in order to generate viable and responsible alternatives for the environment [5]–[7]. In addition to this, it is important to understand how each zone (and its specific use) affects the environment, the potential uses of rainwater and ways of planning specific solutions to each zone (sustainable urban drainage systems - SUDS) which will guarantee optimal results for environmental and flow control [6]. These considerations are fundamental to every country but more so in developing countries, where there are additional technical, economic, administrative, cultural and legal difficulties [8].

Currently, in Colombia, national authorities and research centers are generating policies, initiatives and strategies for the management of urban drainage through SUDS. In a previous work, Peña-Guzmán et al. [9] manifested the need to know about rainwater pollution levels in Bogota, since this could be a potential source of water consumption for the city.

This article presents an evaluation of the influence of land use in the concentrations of different physical-chemical parameters in runoff, through the application of artificial rainfall on three different land uses (residential, industrial and vehicular parking) in the city of Bogotá.

2. MATERIALS AND METHODS

2.1. Geographical area

This article was developed for three scenarios/areas (presenting particular characteristics) in order to analyze the quality of runoff rain water, associated with the activities carried out in each area, and observe the variations of selected parameters in each of the areas. The first example refers to a residential area, located in the Nueva Zelanda neighborhood; the sampling was carried out within a residential complex. It is noteworthy that this area is close to the North Highway and the Northern Portal of the Transmilenio System (main mass transport system). The second area is an industrial zone located in the neighborhood of Granjas de Techo; the sample collection site had a high flow of heavy cargo vehicles. The third scenario refers to a public parking lot in the Chapinero neighborhood.

2.2 Artificial rainfall

To avoid washing of the surfaces by precipitation, the study was carried out in the dry season and, in order to generate consistent concentrations, it was proposed to build a team to simulate rains. This device was intended to simulate the effect of rain on the ground and allow its subsequent flow into the drainage system by runoff. The rain simulator consisted of a rectangular container with a maximum capacity of one gallon, connected to a pump to allow constant flow. To this tank, an evacuation valve was adapted and connected to two 50 cm long PVC pipes, which had perforations 2 cm apart. The rain simulator is shown in Figure 1. To simulate the effect of rain, the container was located 2 m above ground level on a detachable structure of four supports attached to a PVC frame.

2.3 Physico-chemical parameters

We selected physicochemical parameters that are taken into account when used in non-drinking activities in Colombia, these are: Conductivity, Turbidity, Dissolved Oxygen (DO), Total Suspended Solids (TSS), pH, Acidity, Alkalinity, Nitrites, Nitrates, Total and Carbonaceous Hardness and Chemical Oxygen Demand (COD).

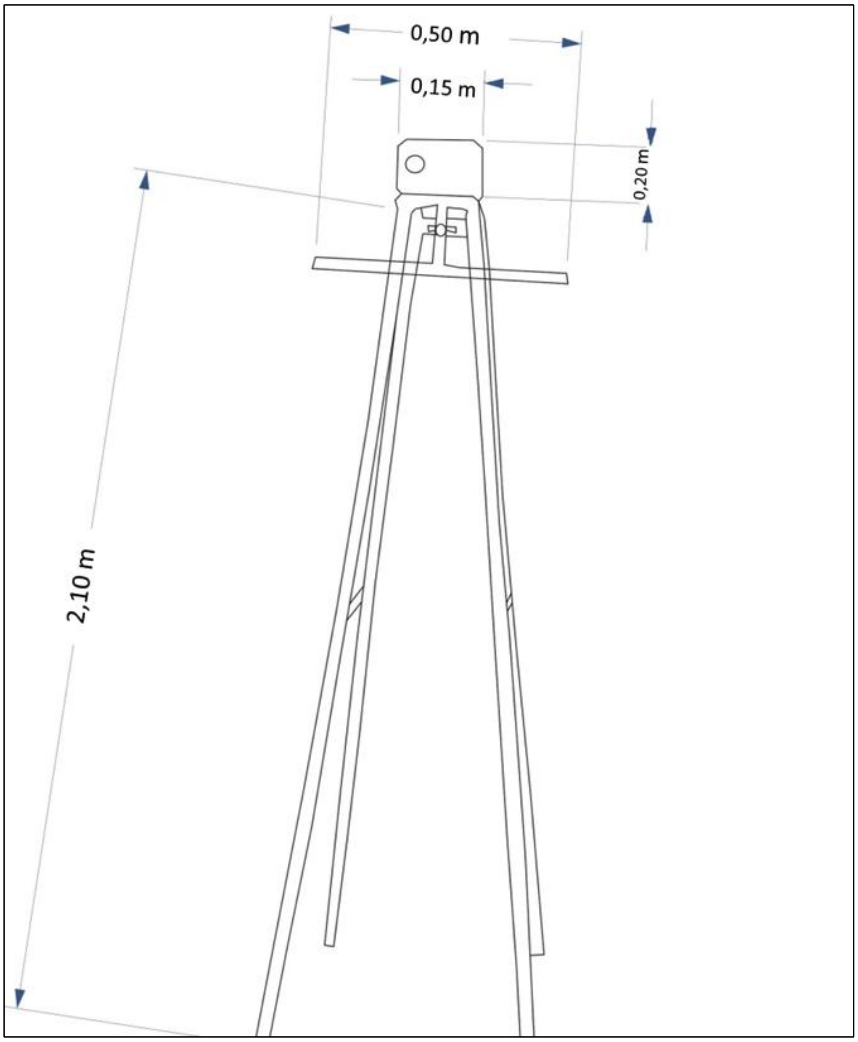

Figure 1. Artificial rain equipment.

2.4 Statistical analysis

Two statistical analyzes were carried out to evaluate the composition of the concentrations obtained and compare them between land uses. It was proposed to carry out an ANOVA analysis in order to compare the results of the influence of land use with respect to the parameters measured. Additionally, a Duncan test was carried out in order to find which parameters behave differently in each land use and to analyze how the variables behave in the three types of soil. For the tests, a p-value of 0.05 was used.

3. RESULTS

Table 1 shows that the industrial zone had the highest concentration values of all the parameters with respect to the other two land uses, with the exception of dissolved oxygen.

According to the results obtained in the laboratory analysis, it was observed that there is a difference in the concentrations for each of the land uses. However, the values of the three zones were between 0 and 5 mg / L, which are very low when directly discharged into bodies of water, although they will have a direct impact on them.

Concerning conductivity, this presented very low values and this may be due to the type of soil in which the sample was taken, which is directly related to its composition. Although parameters such as alkalinity and carbonaceous hardness indicate the presence of carbonates, the low conductivity found might be the result of the reaction of ions forming compounds that impede the conduction of electricity through the medium.

The turbidity in the parking and residential areas behaved in a similar way however, the parking lot contains a higher content of solids due to residues of vehicle emissions and tyre degradation. The industrial zone presented higher concentrations, which are related to the greater quantity of particles coming from certain worn sectors of the roads adjacent to the sampling site as well as those due to the influence of heavy load vehicles, which re-suspend the inert material and deposit it in the area.

Table 1. Summary of concentrations of measured parameters

Parameters	**Land use**	**Min-Max**	**Mean (SD)**
pH	Residential	6.78 to 7.70	7.24 (0.38)
Conductivity (µs/cm)		0.12 to 0.26	0.16 (0.04)
Turbidity (NTU)		10.4 to 35.0	25.10 (7.23)
Dissolved Oxygen (mg/L)		2.51 to 3.43	2.92 (0.30)
Total Suspended Solids (mg/L)		48 to 154	85.6 (34.4)
Acidity (mg/L CaCO3)		11 to 22	14.9 (3.4)
Alkalinity (mg/L CaCO3)		8 to 10	8.5 (0.90)
Nitrates (mg/L)		10 to 50	24.16 (13.95)
Nitrites (mg/L)		0.025 to 0.870	0.14 (0.23)
Total Hardness (mg/L CaCO3)		35.7 to 60.7	49.90 (9.71)
Carbonaceous Hardness (mg/L CaCO3)		8.4 to 42.8	29.70 (8.74)
Chemical Oxygen Demand (mg/L)		110.7 to 212.5	163.2 (51)
pH	Industrial	6.6 to 8.8	7.95 (0.61)
Conductivity (µs/cm)		0.22 to 0.34	0.29 (0.03)
Turbidity (NTU)		178.1 to 325.0	246 (44.2)
Dissolved Oxygen (mg/L)		1.09 to 2.10	1.58 (0.30)
Total Suspended Solids (mg/L)		334 to 888	579.5 (162.5)
Acidity (mg/L CaCO3)		14 to 26	18.8 (3.56)
Alkalinity (mg/L CaCO3)		20 to 30	27.25 (3.38)
Nitrates (mg/L)		50 to 75	58.3 (12.3)
Nitrites (mg/L)		0.5 to 0.4	0.48 (0.03)
Total Hardness (mg/L CaCO3)		85.6 to 104.3	104.28 (14.7)
Carbonaceous Hardness (mg/L CaCO3)		25.0 to 94.6	66.4 (22.4)
Chemical Oxygen Demand (mg/L)		364.2 to 469.4	410.4 (51.5)
pH	Vehicular parking	7.14 to 7.95	7.54 (0.25)
Conductivity (µs/cm)		42.1 to 78.2	59.8 (12.08)
Turbidity (NTU)		0.073 to 0.230	0.14 (0.04)
Dissolved Oxygen (mg/L)		3.25 to 4.37	4.0 (0.33)
Total Suspended Solids (mg/L)		114 to 232	163.9 (36.3)
Acidity (mg/L CaCO3)		2 to 12	8.6 (2.78)
Alkalinity (mg/L CaCO3)		4 to 8	6.85 (1.6)
Nitrates (mg/L)		10 to 50	20.5 (11.7)
Nitrites (mg/L)		0.025 to 0.200	0.05 (0.05)
Total Hardness (mg/L CaCO3)		35.7 to 74.9	49.5 (11.9)
Carbonaceous Hardness (mg/L CaCO3)		12.5 to 50.0	22.2 (9.9)
Chemical Oxygen Demand (mg/L)		37.6 to 52.8	45.4 (7.6)

For alkalinity and acidity, it was observed that industrial land had the highest levels, i.e. the samples found at this location have high concentrations of carbonates and bicarbonates. This may be because of high traffic flow in the area and to the emissions given off by the different companies in the sector. The total hardness analysis indicated that the samples collected were of a mild type.

Nitrites had much higher concentrations in the industrial area than in the two other two areas and the concentrations are associated with discharges to the atmosphere from motor-based oil and the existence of factories engaged in food processing, chemicals and textile industries. As with nitrites, nitrate levels were high in the industrial zone due to the fecal matter, solid waste and decomposing material being discharged by the different companies. As for the parking lot, this parameter was lower since it was in a closed area with constant maintenance. The residential part was influenced by the presence of gardens and the transit of animals, which can contribute to the presence of nitrates.

Sampling in the industrial area indicates that the levels of TSS are very high (similar to values measured in industrial wastewater) and, again, this is due to the emissions from freight and transport vehicles that circulate in the area, industrial emissions and bad practices in the disambiguation of solid and liquid waste reaching public roads.

Finally, the COD reaches significant values in the industrial zone and medium levels in the residential area. In the industrial area, inorganic and organic inputs are high, due to atmospheric emissions and derivatives from ill-disposed raw materials. With respect to the organic portion, it is clear that there is a contribution from fecal material and the inclusion of products from the food and industrial cleaning product sectors.

3.1. Results of the statistical analysis

When evaluating the ANOVA, the significant values showed lower magnitudes of 0.05, which indicates that the concentrations in the land uses studied present statistical differences and that there is a clear relationship between the use of the soil and the concentration of the parameter. This is particularly true for industrial land uses, that showed greater differences in the measured magnitudes. However, there are no large differences between the vehicle parking and the residential sector.

On the other hand, a Duncan test determined that the use of industrial land presents the highest differences in parameters such as: pH, turbidity, nitrates, COD, TSS and OD. Regarding the use of residential land and parking, these tend to be grouped in the same subset since they exhibit similar behaviors; the two land uses behave in a similar way. This is to be expected, taking into account the fact that both land uses share some characteristics such as: the type of vehicular traffic, the presence of vegetation and exposure to the open air. However, the use of the vehicular floor presents better general conditions than the residential, except in the turbidity and the SST present in the water. The parameters that behave differently in the three land uses are pH, OD, turbidity and acidity (where a difference was evident in the three samples).

4. CONCLUSIONS

Evaluation of the sedimentation tests allows us to conclude that land use has a direct influence on the physicochemical characteristics of the runoff water and, for the land use studied in Bogotá, we find that industrial uses tend to generate higher concentrations of the different evaluated parameters; this is associated with the behavior and dynamics of the zone. For this land use, the most relevant parameter differences are found in the presence of nitrogen compounds, total suspended solids, COD and alkalinity. This allows us to determine that the presence of heavy-load vehicular flow and atmospheric emissions are the main factors that influence these concentrations.

The residential area and the parking area presented similar characteristics due to the fact that they were influenced by similar factors, such as the presence of vehicular traffic, pedestrian traffic and plant species. However, some parameters differ between the parking lot and the residential area in that there is a higher concentration of TSS and a lower concentration of COD. This is because in the parking lot, the number of plant species was low, and less than in the residential area.

According to the findings of this study, it is necessary to implement SUDS in order to reduce the pollutant loads which are currently discharged into the city's water bodies. Additionally, the implementation of a sustainable strategy must be carried out by the designers of drainage systems in Bogotá.

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