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Flow Monitoring and Analysis in Sanitary Sewer Systems in Cúcuta, Colombia

Monitorización y análisis de flujo en sistemas de alcantarillado sanitario en Cúcuta, Colombia

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Wastewater, sanitary sewage, maximum flow factor, monitoring

ABSRACT

Monitoring the flow of sewerage systems allows us to know the real behavior of each system and serves as a fundamental tool in wastewater management. For the design of sewerage systems, it is necessary to know the wastewater flows that will be transported by the system and, based on these volumes, the factors that represent the consumption patterns and the characteristics of each community must be estimated. In the absence of information, these factors should be estimated with existing empirical equations developed in research carried out in different cities around the world. The main objective of this research is to estimate the factors specific to the sanitary sewerage system of San José de Cúcuta, for this purpose, the monitoring of the wastewater flow was implemented for 19 weeks, and upon analyzing the data, the hourly variation of the flow entering the system was obtained, and based on the measured flows, a major factor was determined, which represents the characteristics of the city; The factor obtained was also compared with the results of the existing empirical equations and it was possible to identify which of these equations best fit the monitoring campaigns.

Palabras Clave:

Aguas residuales, alcantarillado sanitario, factor de flujo máximo, monitoreo

RESUMEN

La monitorización de los caudales de los sistemas de alcantarillado permite conocer el comportamiento real de cada sistema y sirve como herramienta esencial en la gestión de las aguas residuales. Para el diseño de los sistemas de alcantarillado es necesario conocer los caudales de aguas residuales que serán transportados por el sistema y, a partir de estos volúmenes, se deben estimar los factores que representan los patrones de consumo y las características de cada comunidad. A falta de información, estos factores deben estimarse con las ecuaciones empíricas existentes desarrolladas en investigaciones realizadas en diferentes ciudades del mundo. El objetivo principal de esta investigación es estimar los factores inherentes al sistema de alcantarillado sanitario de San José de Cúcuta. Para ello se implementó el monitoreo del caudal de aguas residuales durante 19 semanas, y al analizar los datos se obtuvo la variación horaria del caudal que ingresa al sistema, y con base en los caudales medidos se determinó un factor mayor que representa las características de la ciudad; el factor obtenido también se comparó con los resultados de las ecuaciones empíricas existentes y se logró identificar cuál de estas ecuaciones se ajusta mejor a las campañas de monitoreo.

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Introduction

The planning and development of cities must consider as a fundamental part, the existing urban infrastructure and the engineering works planned for the future, in this field play a very important role sanitation networks and urban drainage systems [1], which must be built for an established design period and for which the expected future flows must be projected [2]; as well as, its efficient operation, thanks to different factors; such as budgeting adequate maintenance [3]. The projected flows for a region or city have a direct relationship with the variation of the climate, the socioeconomic condition, the number of inhabitants and the habits of life, work and consumption [4].

The proper design of sewerage systems depends on the correct estimation of the magnitude of expected flows in the network and unexpected or poorly projected variation in the range of expected flows can affect the hydraulic performance of some components of sanitation systems, for example, sewage pumping stations, final discharge outfalls and wastewater treatment plants (WWTP), which are designed with the maximum and minimum flows of the system [5], [6]. The appropriate way to estimate the expected wastewater flows is by using information from consumption patterns and existing wastewater monitoring campaigns in each city or community [1], previously carried out at different points of the network. In addition, in which information is available on the hourly variation of the flow, real magnitude of domestic, industrial, commercial and institutional wastewater flows. Also, the factors that represent the characteristics of each system: the return coefficient and the flow increase factor [2], [7]. The reliability of wastewater flow estimates depends on these factors [8].

In the absence of this information, the flow variation and the factors of the system to be designed must be estimated with existing empirical equations, which are the product of research conducted in other cities in the world and that generally differ have very different characteristics to the cities and populations of Colombia [9]. These equations are the result of field measurements and engineering criteria and have as variables the number of inhabitants and the average daily flow of wastewater [10], also taking into account parameters recommended in books on wastewater engineering recognized in the academic world; but the parameters obtained do not adequately represent the behaviour of the system to be designed and can sometimes oversize the components of the drainage system, especially in small cities [11], [12].

To measure the temporal and spatial variation of inflows into sewerage systems, several authors have established different methodologies and some of these allow integrating the variation of wastewater flow rate over time, with the variability of physical and chemical parameters that determine water quality for dry and wet climate conditions [13]. The main objective of this article is to estimate the factors of the sanitary sewerage system of San José de Cúcuta, for this was implemented for 19 weeks and for 24 hours a day, monitoring the flow of wastewater and to perform the analysis of the data measured in the period of measurements, The hourly variation of the incoming flow to the system was obtained, as well as the maximum, average and minimum flows that are contributed to the drainage system, based on the measured flows, the increase factor that represents the characteristics of the city was determined; The factor obtained was also compared with the results calculated using the empirical equations existing in the underlying theory of sanitary sewer design, and it was possible to identify which of these equations best fitted the monitoring data measured in the monitoring campaigns.

Materials and Methods

Wastewater flow monitoring was conducted for 19 weeks (136 days), from October 20, 2019 to March 3, 2020; a single flow measurement point was implemented, identifying a confluence location of a network of collectors of the sanitary sewer system. The network is bounded by topography and forms a natural catchment of the terrain that forms a closed network, whose drainage system converges to a final discharge point or final discharge collector.

For the monitoring campaign an ultrasonic flow meter data logger reference LT-US Sofrel was used, with this meter data was obtained from the incoming flow to the system every 15 minutes, 24 hours a day. The measured data were stored in the internal memory of the device and then transmitted twice a day to a web server (MyWebScada), the specific times of data transmission to the server were previously programmed in the configuration of the equipment. The stored information could be viewed, managed and downloaded.

Rainfall events affect the incoming flow to a sanitary sewer system. If there are erroneous connections, caused by clandestine storm sewer connections that discharge into the sanitary sewer network, there are increases in flow that exceed the hydraulic capacity of the projected collectors, generating overflows on the surface of the inspection chambers [14]. The sanitary sewage system of San José Cúcuta is characterized by the existence of erroneous connections, mainly due to the absence of storm sewers in several sectors of the city; this, despite the fact that for several decades the city has presented multiple characteristics of a very dynamic conurbation [15]; for this reason it was necessary to identify the days of dry weather during the monitoring campaign and with this the days in which rainfall events occurred were discarded.

Two meteorological stations located in areas near the monitored sewage network were monitored. During the same monitoring period, the CAMILO DAZA AIRPORT station [16015010], categorized as main synoptic, and the FRANCISCO DE PAULA SANTANDER UNIVERSITY station [16015110] categorized as main climatic, both stations are operated by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), were constantly consulted.

Study area

The study area is located in the city of San José Cúcuta, Colombia, with a total area of 170.58 hectares and in which communes 3 and 4 are located. The selection of the area was based on the characteristics of the existing sanitary sewerage network, due to the topology in the sector has a closed network with a single point of discharge, which greatly facilitates the monitoring of the flow of wastewater to be performed and additionally in the sector of analysis presents a uniform socioeconomic stratum, giving it a homogeneous characteristic as a study sample.

Maximum hourly flow rate and increase factor

The data obtained in the monitoring campaign allows us to calculate the wastewater flow measured at each hour of the day, obtaining a total of twenty-four (24) flow data per day. For each day of data, the maximum hourly flow value (QMH), the average daily flow (Qmd) and with these two, the factor of increase (FP) is obtained; which takes into account the variations in water consumption by the population and represents the ratio between the QMH and the Qmd. This factor FP, allows to increase the average daily flow in order to establish the peak wastewater flow and project the design flow of the projected sections in a wastewater sewerage network [16]. It is calculated as shown in Equation 1.

$$QMH = Qmd * FP \quad (1)$$

The hourly flow rates obtained for each day of monitoring, allow to elaborate the daily variation curve of wastewater flow and to obtain the hydrograph of incoming flows to the sewage system in dry weather period.

Comparison of the multiplication factor with existing empirical equations

The values obtained for the aggravation factor were compared with the results obtained from existing empirical equations, using equations as a function of Qmd and using the Qmd data obtained for each day of monitoring, thus estimating the aggravation factor for each day, using the equations of Gaines [17] (Equation 2), Utah [18] (Equation 3), Los Angeles [19] (Equation 4) and Tchobanoglous [4] (Equation 5), identifying which of the equations best fits the characteristics of the sanitary sewer of San José de Cúcuta.

$$FP = 6.66/(Qmd*0.168) \quad (2)$$
$$FP = 2.71/(Qmd*0.119) \quad (3)$$
$$FP = 3.53/(Qmd*0.0914) \quad (4)$$
$$FP = 3.70/(Qmd*0.0733) \quad (5)$$

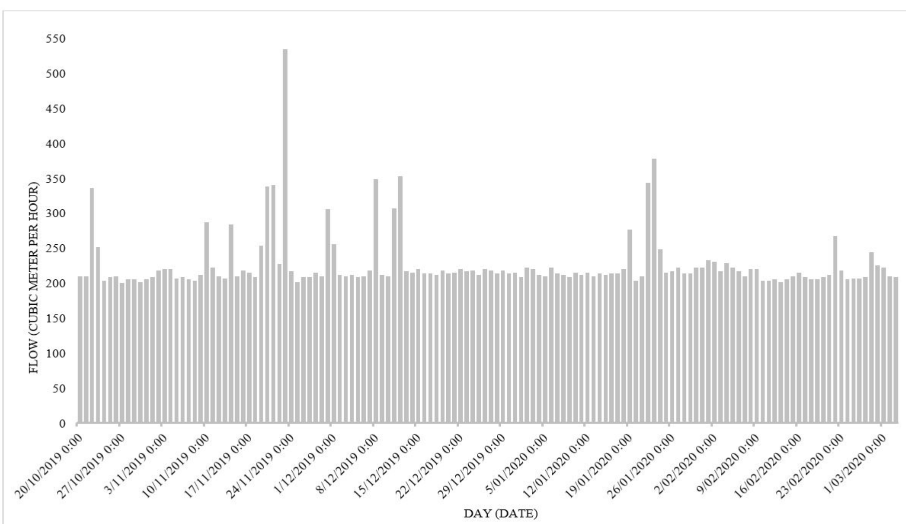
Results and Discussion

The monitoring of the meteorological stations near the study area identified that during the 136 days of monitoring, there were rainfall events on 36 days, therefore, 100 days of data recording were used, corresponding to the dry weather period. Graph 1 shows the total value of the aforementioned monitoring data, and in this graph some flow values can be identified that are greater than the range of average flow values obtained, these values are due to the 36 days of rainfall during the data collection period, the rain is reflected in increased flow in the sanitary sewerage networks due to the existence of erroneous connections that are reflected in increases or peaks in the flow transported by the collectors of the drainage system.

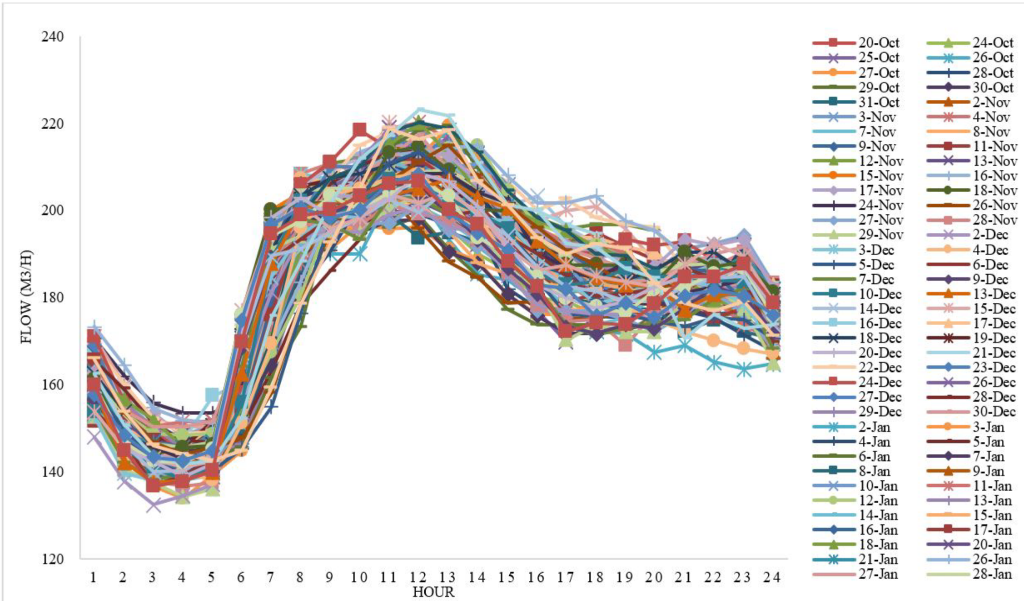
Graph 2 shows the daily variation of the wastewater flow obtained at the analysis site during the time of investigation for the sanitary sewer analyzed. With the flow data recorded at the same time, for the 100 days of dry weather, the hydrograph of inflows to the sanitary sewer was constructed and is shown in Graph 3 [20]. It was determined that the QMH recorded in the study area was 208.67 cubic meters per hour (m 3/h), value recorded at the 12th hour of the day and the Qmd was 181.33 m 3/h, in the same way the PF was calculated, which was 1.15.

The empirical equations existing in the underlying theory of the maximum flow factor and its applicability to the sanitary sewerage system of San José de Cúcuta [21] were evaluated, the initial comparison of the values of PF and Qmd obtained from the 100 days of monitoring, with the values obtained by implementing equations (1), (2), (3) and (4) was performed.

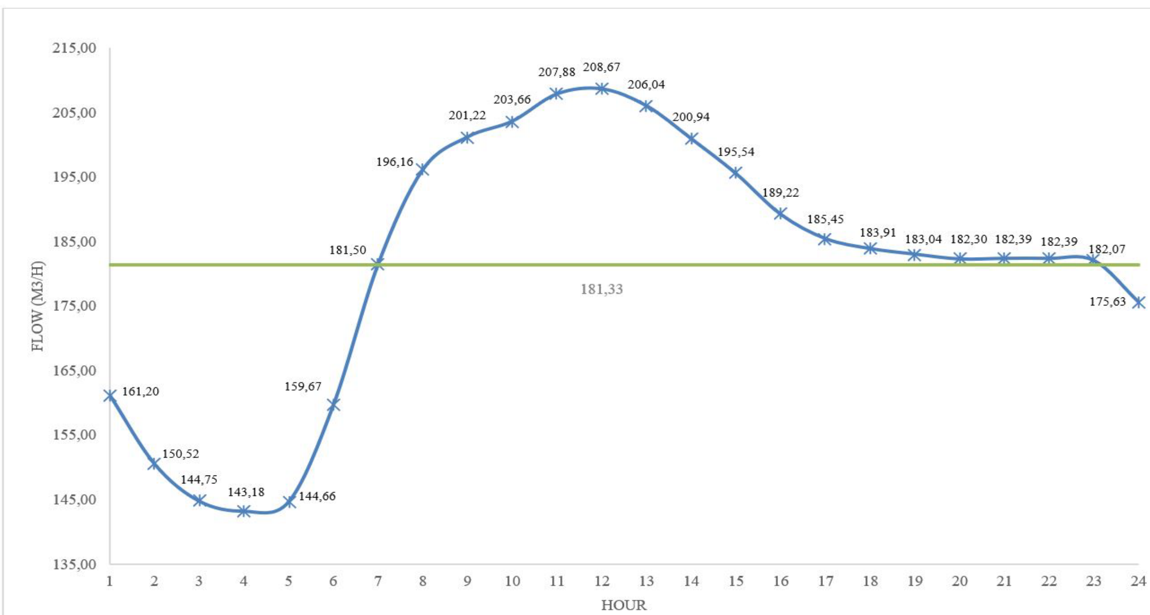
To evaluate these equations were taken into account the different conditions of application and restriction of each of them, which are defined by their authors, these restrictions are due to the application ranges and units of the average daily flow of the equation.



Graph 1. Monitoring of wastewater flow in the sewage system during the measurement period.



Graph 2. Daily variation of wastewater flow in the sewage system.



Graph 3. Hydrograph of incoming flows in dry weather period.

Table I. Comparison of monitoring data with empirical flow factor equations (Gaines, Utah, Los Angeles, and Tchobanoglous).

Day	Qmd [m3/h].	FP Monitored	FP Equation (1)	FP Equation (2)	FP Equation (3)	FP Equation (4)
20 Oct	179.64	1.16	3.45	2.53	2.47	2.78
25-Oct	176.97	1.16	3.46	2.54	2.47	2.78
31-Oct	178.05	1.13	3.46	2.54	2.47	2.78
2-nov	183.45	1.17	3.44	2.53	2.46	2.77
13-Nov	182.05	1.12	3.45	2.53	2.47	2.78
17-Nov	183.90	1.17	3.44	2.53	2.46	2.77
29-Nov	183.78	1.13	3.44	2.53	2.46	2.77
7-dec	186.88	1.16	3.43	2.52	2.46	2.77
9-dec	184.04	1.14	3.44	2.53	2.46	2.77
15-Dec	186.65	1.18	3.43	2.52	2.46	2.77
24-dec	185.15	1.18	3.44	2.52	2.46	2.77
6-jan	182.50	1.20	3.44	2.53	2.47	2.77
14-jan	181.56	1.17	3.45	2.53	2.47	2.78
21-jan	183.34	1.13	3.44	2.53	2.46	2.77
29-jan	185.84	1.15	3.43	2.52	2.46	2.77
3-Feb	185.49	1.15	3.43	2.52	2.46	2.77
11-Feb	175.54	1.15	3.47	2.54	2.47	2.78
20-Feb	180.67	1.15	3.45	2.53	2.47	2.78
27-Feb	181.13	1.15	3.45	2.53	2.47	2.78
29-Feb	183.14	1.22	3.44	2.53	2.46	2.77
1-Mar	181.61	1.21	3.45	2.53	2.47	2.78
2-mar	180.11	1.16	3.45	2.53	2.47	2.78
3-mar	179.21	1.15	3.45	2.53	2.47	2.78

Table I shows the PF values obtained in the monitoring and the PF results obtained by implementing equations (1), (2), (3) and (4), and replacing the Qmd of each day of record. Only 23 values from the total of the 100 days of dry weather monitoring are shown in the table, because of the size of the data it is not possible to present the total data in the research article. These data were chosen randomly, the remaining data present similar results.

It is observed in the results shown that, when using the empirical equations of PF of different authors in the design of sanitary sewers, very different values are obtained from those measured in the monitoring campaigns, as obtained by [11], [22], which are in a range of 1.11 to 1.22. While the range of the results obtained with the equations evaluated ranges between 2.46 and 3.47. Evidencing that the results of the equations analyzed exceed by more than double the value obtained to the result of the PF measured in the field in the sanitary sewer.

Conclusions

The analysis of the data obtained in the dry weather monitoring campaign, allowed estimating the QMH recorded at 12 hours of the day with a value of 208.67 m 3/h, it was also possible to calculate the Qmd which yielded a value of 181.33 m 3/h. When calculating the relationship between QMH and Qmd, known as the PF for the city of San José de Cúcuta, a value of 1.15 was obtained; this value is lower than the range recommended by Colombian regulations, which is 1.4 to 3.8.

When evaluating the Gaines Utah, Los Angeles and Tchobanoglous equations, currently used in the design of sewerage systems in Colombia, it was possible to establish that the results obtained show a behavior different from the measured values. It is demonstrated that none of the methodologies recommended in the underlying theory adjusts to the behavior of the incoming flows to the sanitary sewer analyzed and therefore it is necessary to continue implementing wastewater flow measurements in order to obtain the characteristics of the system.

The range of the PFs measured in the monitoring of the sanitary sewer of Cúcuta was 1.11 to 1.22, while the range of the results of the equations evaluated was between 2.46 and 3.47, showing a percentage increase in the PFs obtained by equations that varied between 203% and 309% with respect to the monitored PFs. The existing difference could have a significant influence on the estimation of design flows, on the oversizing of the components of the drainage system and on the cost of implementing urban drainage projects.

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