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ESTIMATION OF DOMESTIC WASTEWATER CHARACTERISTICS IN A DEVELOPING COUNTRY BASED ON SOCIO-ECONOMIC VARIABLES

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ABSTRACT

The paper presents the analysis of data related to the domestic wastewater characteristics from several areas situated in a large Brazilian city. Simple regression models are presented for the prediction of basic wastewater characteristics, such as *water consumption* (l/inhab.day), *wastewater production* (l/inhab.day), *BOD load* (g/inhab.day) and *BOD concentration* (mg/l). The models are based on simple socio-economic variables, with special attention to the easily obtainable variable of *total family income* (number of minimum salaries earned per month). Most of the models are able to give an excellent prediction of the desired wastewater variables. Additionally, the behaviour of the main wastewater characteristics according to the hour of the day and the day of the week are analysed. Based on the results obtained, it is suggested that the classical figures of BOD concentration of 300 mg/l and per capita BOD load of 54g/inhab.d do not apply to the typical population predominant in most areas of Brazil. The actual BOD concentrations are frequently higher than 300 mg/l, while the BOD load is frequently lower than 54 g/inhab.d. The results obtained can be used for design purposes in the areas studied, and possibly in areas of similar characteristics, substituting the classical figures obtained from foreign textbooks. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Biochemical oxygen demand; developing countries; domestic sewage; wastewater flow; wastewater characteristics; water flow.

INTRODUCTION

The design of wastewater collection, treatment and disposal systems in developing countries is usually based on parameters imported from the literature, reflecting the experience of developed countries. Local consultants, in the absence of reports of consistent local data, tend to overcome the problem by adopting classical parameter values from well-known foreign textbooks. International consultants working in developing countries, also with the difficulty of gathering local information, frequently accommodate themselves by utilising the same parameters adopted in their home countries. In both cases, the incentive of using any locally available data is surpassed by the apparent safety generated by the referencing of a classical textbook. The usual result is the oversizing of systems, units and equipment, with an obvious wastage of valuable financial resources, together with the risk of malfunctioning due to excessive retention times. In some cases, the opposite situation of an underdesign can also occur, bringing process failures due to overloading.

Aiming at obtaining design parameters for wastewater systems reflecting more closely the local reality, COPASA-MG, one of the major water companies in Brazil, undertook an extensive research programme involving data collection and analysis in selected areas of the city of Belo Horizonte. This city is currently the fourth in population in Brazil, with a population around 2 million inhabitants.

This paper utilises the data collected in the field studies, extending their interpretation by statistical analysis. Simple models are presented for the prediction of basic wastewater characteristics, such as *water consumption* (l/inhab.day), *wastewater production* (l/inhab.day), *BOD load* (g/inhab.day), *BOD concentration* (mg/l). The models are based on simple socio-economic variables, with special attention to the easily obtainable variable of total family income (number of minimum salaries earned per month). The results are associated with predominantly *residential wastewater*. Additionally, the behaviour of the main wastewater characteristics according to the hour of the day and the day of the week are analysed.

METHODOLOGY

The field work was carried out from September 1986 to July 1987 in the two main catchment areas of the city of Belo Horizonte. Nine large areas were selected, and further grouped into five socio-economic classes, representing total family income, housing standards and type of land occupation. In each area, a sub-area was selected, such that the requirements of representativeness and of ease of collection were fulfilled. The sub-areas selected were small and essentially residential. The wastewater collection system is of the separate type.

On average, four data collection campaigns were done per area, with a duration of two weeks each. A broad range of hydraulic, environmental, physical, chemical and biological data were collected. The present paper uses only BOD and flow, together with the results from house questionnaires applied in the same period of the monitoring. Grab samples were used for BOD concentration, while composite samples were used for per capita BOD load. Instantaneous flow readings were used for the study of the hourly flow variations, while daily averages were adopted for the analysis of the daily flow variations.

The questionnaires covered information such as water consumption (reading of water meters), number of street connections, type and quantity of sanitary basins, number of residents per sex and age, instruction level and areas of the lot and of the construction.

Table 1. Average values for each sampling area

Area	Population (inhab)	Total income (number of minimum salaries)	Water consumption (l/inhab.d)	Wastewater production (l/inhab.d)	BOD load (g/inhab.d)	BOD concentration (mg/l)
A	286	18.6	233	208	56.4	249
B	881	10.5	193	143	51.4	257
C	3012	10.9	230	142	38.9	280
D	747	5.8	139	81	30.0	324
E	991	7.5	179	127	48.7	302
F	1412	5.0	134	101	27.4	215
G	906	4.7	128	105	46.8	358
H	2133	3.0	100	87	36.0	413
I	2919	1.9	86	71	33.5	472

Note: Minimum salary: US$ 100 per month

RESULTS

Average values

Table 1 presents the average values for each sampling area of some of the more relevant parameters.

Infiltration flow

The infiltration was assumed as being the minimum flow occurring in the period from 0:00 am to 6:00 am. It is known that this inference can lead to errors of larger or smaller scale, depending on the area under analysis. However, it was judged that the low length of the collection system (< 1.5 km) and the small population contributing in the late night hours make the assumption very close to reality, since any small flow variation in this period could be considered as coming from some house. Naturally, this is only possible with low flows. Table 2 presents the infiltration rate for each area.

Table 2. Infiltration rate for each area

Area	Infiltration per length of collection system (l/s.km)	Infiltration per area (l/s.ha)
A	0.075	0.015
B	0.056	0.013
C	0.388	0.068
D	0.016	0.003
E	0.010	0.002
F	0.040	0.006
G	0.148	0.031
H	0.475	0.100
I	0.130	0.027

Note: Area G: wet weather

The higher values were found in areas C and H. In area C, the probable cause is the large age of the network. In area H, the proximity to a stream is the most probable cause. In the other areas, the infiltration rate per length was much lower than the figure of 0.3 l/s.km, recommended in many textbooks and codes of design.

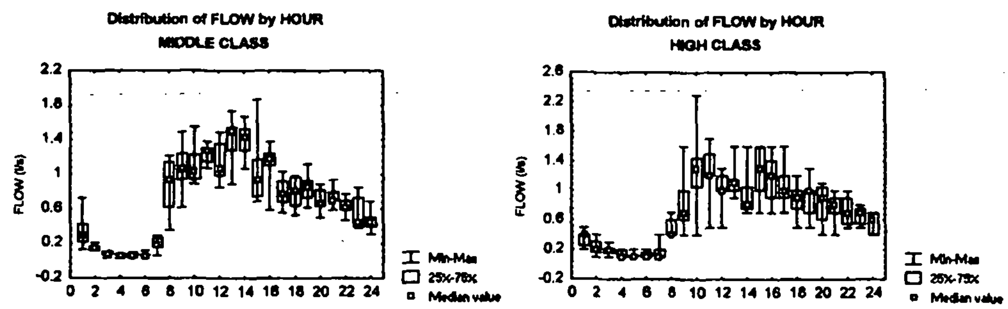

Figure 1. Hourly variations of sewage flow during the day.

Variations in flow

As expected, a typical pattern for the hourly variations of flow was detected. In general, the minimum flow starts around 0:30-1:00 am and finishes at 6:00 am in the lower classes and at 6:30-7:00 am in the other areas. This reflects well the behaviour of the population, with an early rising of the workers in the low class areas, which are more distant from the working place. Figure 1 illustrates the diurnal pattern in area A (high class) and area E (middle class).

Figure 2 presents the sewage flow variatios per day of the week (Sunday = 1, Monday = 2 etc) in the same two areas analysed above. Even though the average flows are approximately the same, in the high class area the variability within all the days is much higher.

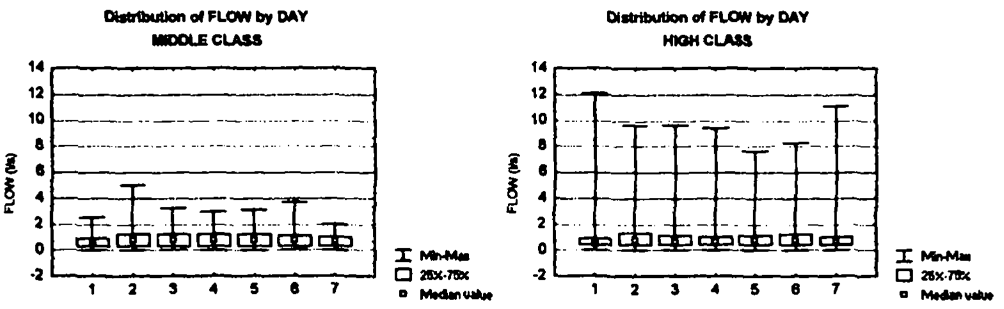

Figure 2. Daily variations of sewage flow during the week.

Table 3 presents the calculated values of K_1 (coefficient for the day of maximum wastewater production) and K_2 (coefficient for the hour of maximum wastewater production). The values are well above the typical values recommended in the literature for water consumption ($K_1 = 1.2$ and $K_2 = 1.5$), emphasising the well-known fact that for small populations the variability is much more pronounced. It can also be seen from Table 3 that the coefficients tend to decrease with the increase in population. The K_2 values derived are smaller than those obtainable by Harmon's formula ($K2 = 1 + 14/[4+ (Pop/1000)^{0.5}]$.

Table 3. Coefficients K_1 and K_2 for each area

Area	Population (inhab)	K_1	K_2	K_1xK_2
A	286	1.38	2.52	3.48
B	881	1.47	2.06	3.03
C	3012	1.35	1.94	2.62
D	747	1.33	2.19	2.91
E	991	1.49	2.32	3.46
F	1412	1.37	2.18	2.99
G	906	1.16	1.61	1.87
H	2133	1.30	2.08	2.70
I	2919	1.16	1.95	2.26

Variations in BOD

Figure 3 illustrates the hourly variations of the BOD concentration. In the middle class area the pattern is very similar to the hourly flow pattern, with small variations from 0:00 am to 6:00 am. In the high class area the pattern is very irregular, different from the flow pattern and with a wide variation from 0:00 am to 6:00 am. This reflects the more systematic and similar behaviour of the middle class population in terms of distribution of activities during the day.

The daily variations of BOD concentration during the week can be seen in Figure 4. Visually it is seen that there is not much variation from day to day. This comment is supported by the analysis of variance, which rejects the hypothesis that the mean values of the concentrations for each day of the week are significantly different. The probability levels obtained are: 0.688 for the high class area and 0.184 for the middle class area (p-values greater than 0.05 indicate that the hypothesis of different means can be rejected).

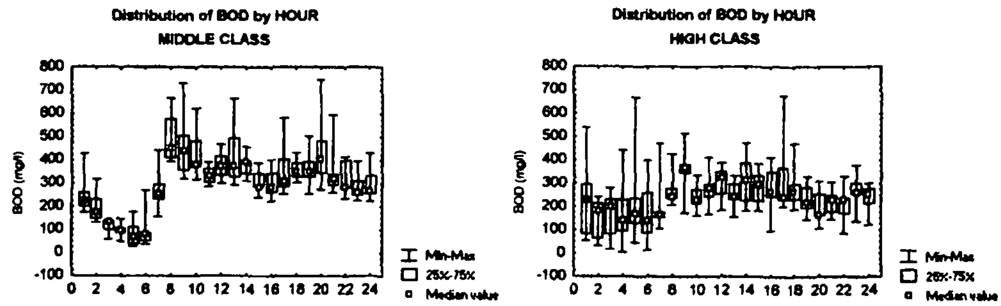

Figure 3. Hourly variations of BOD concentration during the day.

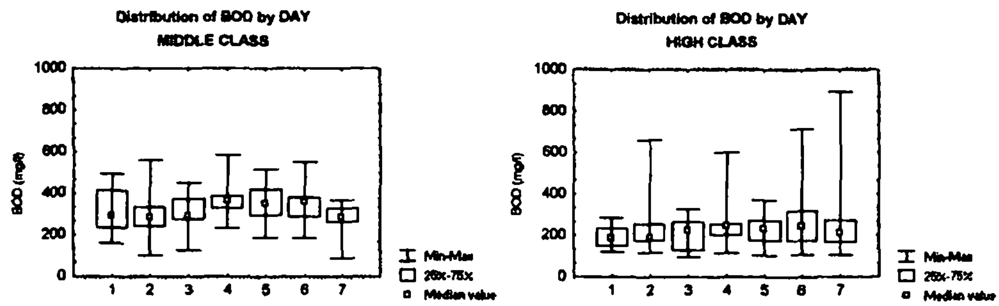

Figure 4. Daily variations of BOD concentration during the week.

Table 4. Proposed regression models

Variable to be estimated (y)	Independent variable (x)	Equation	R^2
Per capita water consumption (l/inhab.d)	Number of minimum salaries per month	$y = x/(0.021+0.003*x)$	0.942
Per capita wastewater production (l/inhab.d)	Number of minimum salaries per month	$y = 57.9 + 8.0*x$	0.966
BOD_5 concentration (mg/l)	Number of minimum salaries per month	$y = 247 + \exp(5.91 - 0.26*x)$	0.992
Per capita BOD_5 load (g/inhab.d)	Number of minimum salaries per month	$y = 32.9 + 1.25*x$	0.518
BOD_5 concentration (mg/l)	Per capita water consumption (l/inhab.d)	$y = 131 + 28589/x$	0.965

Estimation of flows and BOD based on socio-economic variables

Several regression models were tried, in order to correlate the main design variables with socio-economic variables of easy collection. The paper presents only the correlations of flows and BOD with the economic variable of easier derivation, which is the average number of minimum salaries earned by family per month. In Brazil, the minimum salary is currently around US$ 100. The best-fitting models are presented in Table 4 and in Figure 5. In general, the fitting was very good, as can be seen from the high values of the Coefficient of Determination (R^2).

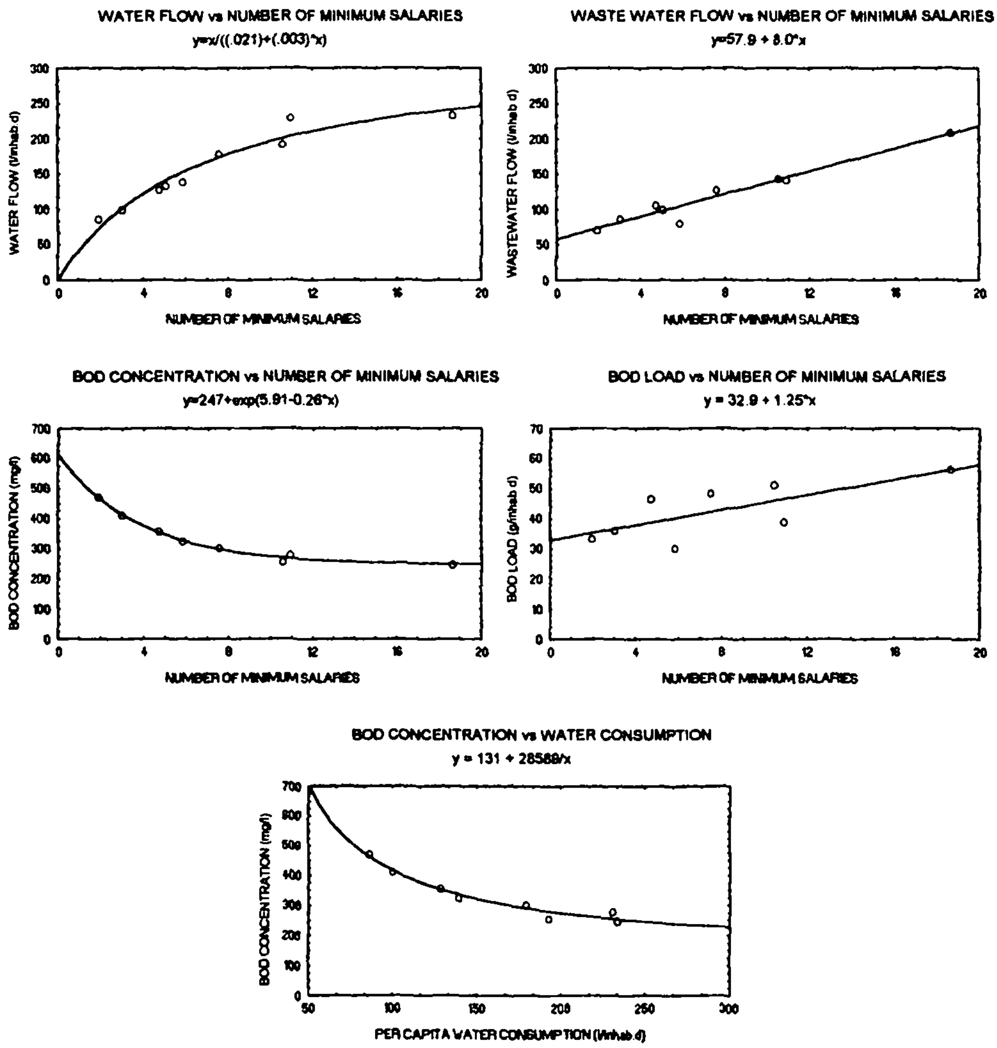

Figure 5. Observed and estimated values according to the proposed regression models (1 minimum salary = US$ 100).

According to the model obtained, the BOD concentration of 300 mg/l, which is frequently quoted as the typical one for domestic wastewater, is obtained for a total income of 7.5 minimum salaries (US$ 750/month). Also based on the derived model, the typical figure of 54 $gBOD_5$/inhab.d is achieved at a total income of 16.9 minimum salaries (US$ 1690). In this case, the two figures are inconsistent with each other, different from what is considered in most textbooks.

Based on the data presented and on the authors' experience, the typical BOD concentration in Brazil is higher than the classical figure of 300 mg/l. More typical values are in the range of 350 mg/l. It is also believed that the typical per capita BOD loads are lower than 54 g/inhab.d, given the low to medium family income predominant in Brazil.

CONCLUSIONS

The *per capita* values of *water consumption* and *wastewater production* can be well estimated from the total family income.

The *BOD concentration* can be well predicted from the total family income or from the per capita water consumption.

The *per capita BOD load* can be reasonably estimated from the total family income.

The main variable used for the prediction (*total family income*) is a convenient one, given its ready availability in most studies.

Considering that most of the Brazilian population has a low to medium income level, the typical values of BOD concentration are higher than the usual figure of 300 mg/l, while the typical per capita BOD load is lower than the classical value of 54 g/inhab.d.

The specific conclusions derived in the paper are limited to the conditions in which the data were obtained: predominantly residential wastewater (negligible trade or industrial wastes) from a separate collection system in a large urban area. However, it is believed that the general principles can be extrapolated to other cities in Brazil, since they have approximately the same living standard and pattern as those from Belo Horizonte.

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