Domestic Wastewater Characterization by Emission Source

C. Boutin* and C. Eme**

* Freshwater systems, ecology and pollution research unit, Irstea, 5 rue de la Doua, BP 32108, 69616 Villeurbanne Cedex, F (E-mail: catherine.boutin@irstea.fr)
** CreaPure, Oxalis SCOP, ingénierie écologique, 603 boulevard Président Wilson, 73100 Aix les Bains, F

Abstract
Historically, domestic wastewater has been split into two main categories: blackwater and greywater. We set out to characterize domestic effluent more finely in terms of specific pollution emission sources: urine, faeces, toilet paper, cooking, bathroom and laundry effluent, etc. This more detailed characterization helps to provide a more thorough knowledge of domestic wastewater composition and its variability. This literature review makes an inventory of scientific papers characterizing household effluents by emission sources in Western Europe, in contexts similar to France. A critical reading is made, covering analysis protocols and sampling methods.

Results are also compared with national data for small communities. In volume terms, greywater is the main contributor to domestic wastewater. Faeces and toilet paper supply most of the organic matter. Nitrogen comes mainly from urine, and phosphorus mainly from greywater generated by food-related and cleaning activities.

The nutrient balance of each effluent, represented in this study by the ratios BOD_5:N,P, allows an estimation of its response potential with regard to biological treatment. The evaluation of nutrient balance reveals chronic nutrient deficits in greywater for a biological treatment. However, such treatment is favoured by the biodegradability and nutrient balance of human excreta in blackwater.

With the aim to optimize wastewater uses by treating or recycling specific domestic effluents, this work provides a database with ranges of variation and knowledge for a fuller understanding of processes.

Keywords
Domestic sanitation; faeces; greywater; biological treatment; source separated; urine.

INTRODUCTION

Wastewater characterization by emission source involves fine expertise with daily use surveys and robust field campaigns at household scale. These practices imply important studies costs and set limits to research activities. Knowledge of domestic wastewater and its range of variation enable to optimize treatment units design in a real-world context. Domestic wastewater from a collection network differs from domestic effluent generated by individual users and in that; it contains no clean water or rainwater intrusion, or agricultural or industrial contributions. Collected domestic wastewater is relatively well characterized, whereas the effluent actually released at habitat scale has been less described, owing to broad variability among users. In the context of the development of projects for reclaiming and re-using domestic wastewater, and in particular separation at source, this review describes a characterization of domestic effluents by emission source. To improve wastewater treatment and consider new alternatives in the French context, an improved understanding of wastewater emission sources is required. Here we present a bibliography review of domestic wastewater production and quality at household scale.

Classification

The characterization of domestic wastewater by emission source implies differentiating all source locations where wastewater is produced at household scale.

Figure 1. Classification of domestic wastewater

Blackwater. For blackwater, two modes of effluent collection are considered: classic collection of whole excretion and water from toilets, and selective collection from source-separating toilets which are usually composed of a faecal bin and an urine diverter. Unlike classical toilets, source-separating toilets allow a separate collection of yellow water (flush water and urine) and brown water (flush water or not, faeces and toilet paper). Contributions considered as accidental, such as cleaning water in toilets, cigarette butts, *etc*. are also taken into account.

Greywater. Greywater includes various emission sources. Effluent characteristics are linked to appliances used and to individual patterns: kitchen sink, dishwasher, washing machine, bathroom washbasin, shower, and bath. These uses are divided under two headings: (i) greywater from food-related activities and cleaning (kitchen and laundry activities), and (ii) greywater from personal care, bathroom effluents.

MATERIALS AND METHODS

The datasets presented (more than 80) come from scientific publications dealing with strict domestic effluent or medical characterization of human excreta. They all concern exclusively Western Europe.

They cover only strict domestic water uses. Facing a broad diversity of published work, a critical reading was undertaken, which revealed variability in the methods for surveys and assessment used.

Datasets considered in this study are not often detailed in their original publication. The statistical material presented offers only partially exploitable data. However, an inventory of the data averages allows the average composition of each emission sources to be established, with minima, maxima and range variations of this average.

Each effluent is characterized by the quantification of loads in grams per person per day, implying the integration of the dweller's occupancy time to obtain a daily estimate over 24 h. Effluent concentrations were evaluated when dataset are adequate

This article concerns mainly the classical parameters (COD, BOD_5, DM, SS, N, and P), although the bibliography also covers some micropollutants, metals and sanitary indicators (Eme C. *and al*, 2015).

RESULTS AND DISCUSSION

Blackwater

Few (<10) consolidated datasets are available to separately characterize urine (whether hydrolysed or not), or faeces. Each contribution made by blackwater was evaluated in grams per person per day, given the difficulties in quantifying concentrations of faeces and toilet paper. The sum of all the flows slightly exceeded the overall measured composition of the blackwater. Blackwater flows are generally measured per inhabitant, without correcting for occupancy time, whereas a separate source is evaluated per person for a 24 h period. Analytical errors may add to this discrepancy.

Volumes of blackwater generated vary appreciably according to flush type. The identification of the different types of flush gave an average rate of dilution of excreta in blackwater of 1:27 for a classical toilet (Eme C. *and al*, 2015).

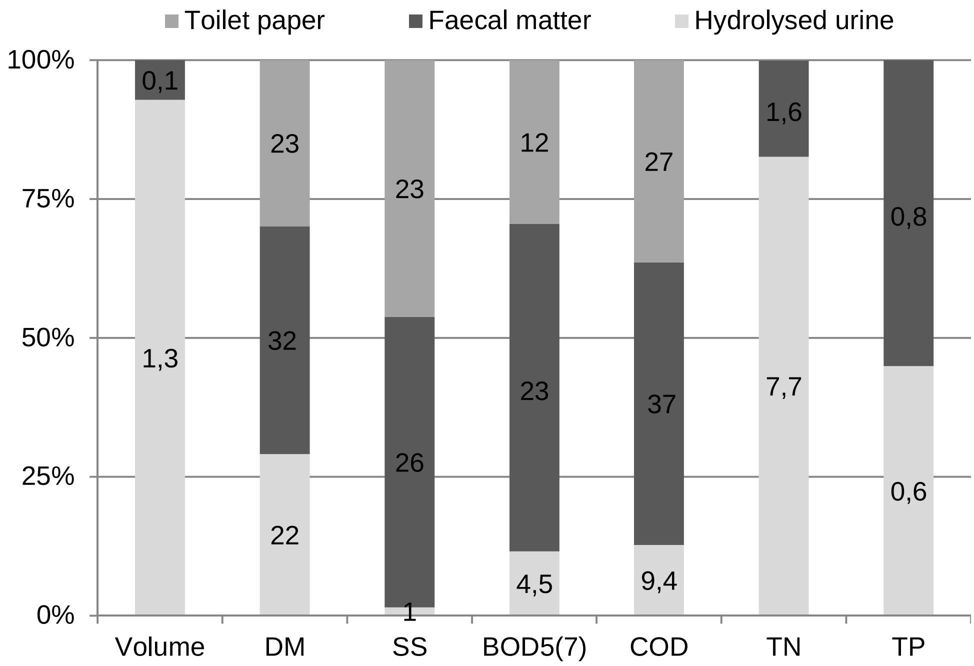

Figure 2. Load distribution in blackwater in $L.pers^{-1}.day^{-1}$ for the volume (without taking flushes into account), and in $g\ .pers^{-1}.day^{-1}$ for the other variables

The main contributors of suspended organic matter were faeces and toilet paper. Urine was the main contributor of nutrients. Toilet paper made up nearly 50% of SS. Heavy metals, when assayed, came mostly from service piping. The micropollutants identified came from pharmaceuticals and their metabolites, preferentially eliminated in urine. The presence of pathogens in the blackwater contributions is very often associated with faeces and the contamination of other sources by them.

About half the organic matter contained in blackwater comes from faeces and more than 30% from toilet paper. Hydrolysed nitrogen comes essentially from urine; phosphorus comes equally from urine and faeces.

Greywater

52 datasets were used to characterize greywater. They include effluents from personal care and effluents from food-related and upkeep activities. Data related to personal hygiene are more abundant. To evaluate of the contribution of each water end-use, various methods are implemented through bibliography. Long and fastidious surveys are generally required. Among them, some can use ‘direct’ monitoring by assessing the production of effluents combined by on-site sampling. Others imply ‘indirect’ monitoring by following selective consumption of drinking water uses by dairy surveys or flow meters and/or modelling the use of household fixtures and appliances.

Variability of greywater composition (Table 1) occurs at several scales, with main different habits at social, temporal and spatial scales. The average production of wastewater is 86 L per person per day, with about 47% attributed to personal care and 53% to food-related and cleaning activities. Physically and chemically, greywater composition presents low values of BOD_5, COD, SS and nutrients, but with very broad ranges of variations.

Table 1. Composition of greywater from data collected

Parameter	Unit	Data collected[1]		Range of variation[2]	
		average	number of values	minimum	maximum
pH	-	7.5	23	6.1	9.6
Conductivity	$\mu S.cm^{-1}$	561	11	65	3000
Turbidity	NTU	69	18	5	462
DM	$mg.L^{-1}$	582	7	44	879
SS		89	20	20	361
BOD_5		221	27	20	756
COD		362	29	25	1583
TOC		99	10	10	600
TN		14	17	3	75
OrgaN		7	1	7	7
NH_4^+-N		3	2	1	13
NO_3^{2-}-N		3	11	0	10
KN		1	9	0	27
TP		4	10	0	11
PO_4^{3-}-P		12	15	0	101
K		9	1	5	23
S		72	1	18	72
Surfactants		13	5	0	118

1: averaged average literature values collected;
2: minimum and maximum of all the data collected

Comparing the different sources of greywater (bathroom, kitchen and laundry), a qualitative difference is seen for BOD_5, COD and SS concentrations. Laundry effluents (BOD_5: 567 $mg.L^{-1}$) are more concentrated than bathroom effluents (BOD_5: 131 $mg.L^{-1}$); even so, mass pollution from personal care represents 20% of greywater.

Reconstituted wastewaters

From all previous considerations, a proposal of domestic wastewater reconstitution is presented (table 2). Domestic wastewater reconstitution presented below is compared to National datas.

A complementary reconstitution has been also realized (Eme C. *and al*, 2015) cumulating blackwater and greywater datasets. but is not presented here. This second reconstitution had permit to validate previous results.

Domestic wastewater cumulated loads achieved respect the same order of magnitude as the average composition of domestic wastewater met in small communities (< 2000 PE) measured at the wastewater treatment plant.

Table 2. Reconstitution of the quantity and quality of domestic wastewater from collected data (expressed in $L.pers^{-1}.d^{-1}$ and in $g.pers^{-1}.d^{-1}$).

Variable		Blackwater			Greywater		Sum of contri-butions	Collective treatment reference
in $L.pers^{-1}.d^{-1}$ or $g.pers^{-1}.d^{-1}$		hydro-lysed urine	faeces	toilet paper	personal hygiene	food-related and cleaning		
Volume (L)	of flush depending on equipment		6 - 73				89 - 156	-
Volume (L)	with flush	-	36.0	-	39.0	44.0	119.0	-
Volume (L)	without flush	1.3	0.1	0.0	39.0	44.0	84.4	-
Parameters (g)	SS	1	28	23	3	15	67	72[b]
Parameters (g)	BOD5(7)	5	23	12	5	21	65	60[a]
Parameters (g)	COD	9	37	27	8	52	133	156[b]
Parameters (g)	TN	7.7	1.6	0.0	0.3	0.8	10.4	15.0[b]
Parameters (g)	TP	0.6	0.8	0.0	0.0	1.2	2.6	2.0[b]
Parameters (g)	of which PO_4^{3-}-P	0.7	0.4	0.0	0.1	0.6	1.7	-

a) from Council Directive 91/271/EEC in $g.(Person\ Equivalent)^{-1}.d^{-1}$

b) from Mercoiret, L., 2010 and considering 1 $inhab.d^{-1}$ in BOD_5 = 1 Person $Equivalent.d^{-1}$

The contribution of greywater is greater in volume. Faeces and toilet paper supply most SS and organic matter, with an appreciable contribution from greywater arising from food-related and cleaning activities. Nutrients mostly come from urine (nitrogen), and laundry water, faeces and urine (phosphorus).

This study underlines that greywater forms at least 25% of domestic wastewater pollution (except for nitrogen). Its volume contribution is always dominant, even when flush volume is not optimized.

Biodegradability and nutrient balance for biological treatment

Data presented come from the literature, and as complete datasets are lacking, only minima, means and maxima are considered.

In the presence of nutrients, the COD/BOD_5 ratio is a measure of how much easily total biodegradable organic matter is present in effluent. The COD/BOD_5 ratios in the data collected suggest that urine is most easily biodegraded, followed by faeces and then greywater, with a broad dispersion of data for this last type of effluent.

The absence of data for $BOD_{ultimate}$ or inert residue limits the characterization of the overall biodegradability of the effluents. The biodegradability and balanced organic matter and nutrients of human excreta seem to favour biological treatment. However, additional analysis is necessary to integrate, in particular, $BOD_{ultimate}$ and inert residue.

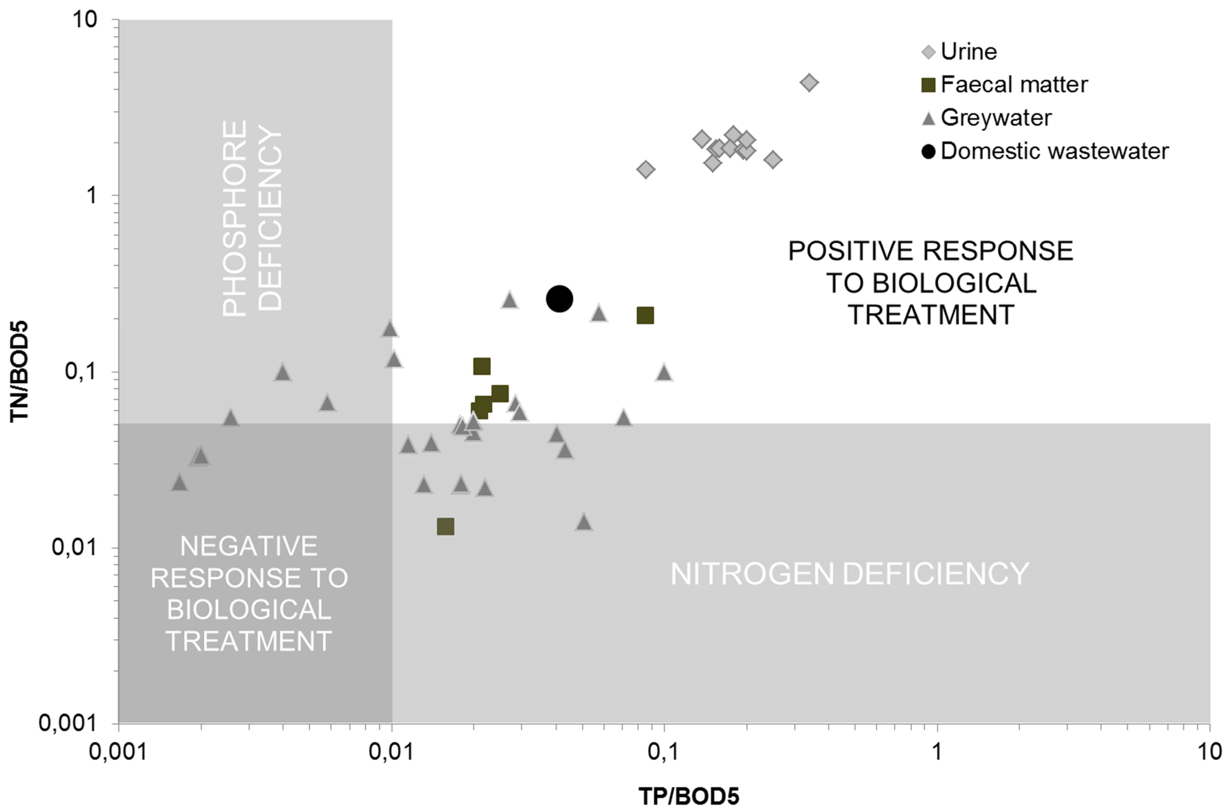

Figure 3. Domestic effluents and biological treatment (all data collected)

Figure 3 illustrates the TN/BOD5 and TP/BOD5 ratios for the different effluents generated at the domestic scale. An evaluation of the nutrient balance of effluents, represented by the ratios BOD_5:N,P, indicates their suitability for treatment: the regular nutrient deficiency of greywater makes it a poor medium for the bacterial growth necessary for its biological treatment.

CONCLUSION

This domestic wastewater characterization considers maximum household uses such as human excretion (urine and faeces), toilet paper use, kitchen effluents, bathroom effluents and laundry effluents.

The reconstitution of domestic wastewater using cumulated data from emission source gives values of the same order of magnitude as those for domestic wastewater in small communities. However, care must be taken to differentiate between person and inhabitant: confusion is apparent in the studies considered, some taking into account occupancy of inhabitants, others not.

Protocol homogeneity between different studies would facilitate average wastewater characterization and improve the understanding of processes. Differences in protocols (in particular for the characterization of SS and for BOD_5, with few publications stating whether or not allylthiourea (ATU) was used) must be more fully taken into account to make a finer estimation of true wastewater composition.

The evaluation of the nutritional balance of effluents, represented by the ratios BOD_5:N,P, allows an estimate of their potential responsiveness to biological treatment: the regular deficiency in nutrients of such greywater makes it unable to support the bacterial growth necessary for its biological treatment.

These conclusions are drawn from the average and extreme values of existing datasets. Household consumption is changing: this database will need to be extended for each type of effluent to integrate changing user behaviour and new regulations, and refine the technical adaptations required for the treatment and gainful re-use of each of these effluents.

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