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Exploring a New Approach of the Population Equivalent Concept through a Detailed Characterization of Grey and Black Waters

G. Nsavyimana[1,5*], S. Kaboneka[2], P. Bigumandondera[3,5], E. L. Ngahane[4], T. Ndikumana[1,5] & J. L. Vasel[4]

[1] University of Burundi, Faculty of Sciences, Department of Chemistry, P.O. Box 2700 Bujumbura, Burundi.
[2] University of Burundi, Faculty of Agriculture and Bio Engineering, Department of Environment Sciences and Technologies, P.O. Box 2940 Bujumbura, Burundi.
[3] University of Burundi, Applied Institute of Pedagogy, Department of Chemistry, P.O.Box 5213 Bujumbura Burundi
[4] University of Liege, Department of Science and Environmental Management, P.O. Box 6700 Arlon, Belgium
[5] Natural Sciences and Environment Research Center/ University of Burundi

ABSTRACT

Reliable and accurate data from on-site facilities are important for modelling the biochemical processes occurring in wastewater treatment bioreactors. This study aimed to redefine the concept of population equivalent through a detailed analysis of grey and black waters. The concept of population enables the determination of the overall pollutant load from various houses connected to a collective treatment plant. Several chemical compounds and physicochemical parameters including lipids, total nitrogen, proteins, carbohydrates, and total chemical oxygen demand (COD), were assessed in grey and black waters samples collected in Belgium and Burundi, and expressed in population equivalent unit. Our results showed that the total COD corresponding to one population equivalent unit in Burundi and Belgium was 117.08±10.09 g COD/capita/day and 138.75±20.09 g COD/capita/day, respectively. The total COD in Belgian experiments was distributed as 34.26% for faeces, 19.01% for waters from kitchen sinks, 16.26% for the grey waters from the laundry, and 10.97%, 15.36% and 4.14% for toilet paper, shower soaps and urine, respectively. Results from Burundi samples revealed that laundry detergents, toilet paper and shower soaps were 14.70±0.40 g/capita/day, 12.20±0.40 g/capita/day and 5.00±0.30 g/capita/day, respectively. The quantity of the main chemical compounds in both grey and black waters ranged from 0.37±0.18 to 35.17±6.82 g/capita/day, with average values of 8.33, 10.37, 17.75, 12.27, and 35.17 g/capita/day for lipids, total nitrogen, laundry detergents, proteins and carbohydrates, respectively. Our findings are valuable information that can be explored for the determination of the "complex substrate biomole" formula, which is useful for modelling the processes involved in wastewater treatment.

Key Words: Wastewater, Black waters, Grey waters, Population equivalent, Eco sanitation.

1. INTRODUCTION

Wastewater treatment is a major concern worldwide including developing countries. The use of on-site sanitation systems (e.g. septic tanks) for domestic wastewater treatment constitutes an alternative where collective systems are not achievable [1, 2]. In developed countries, on-site sanitation systems are usually exploited in areas where connections to a collective treatment plant via a sewer network cannot be done for either technical or economical reasons [3, 4]. While in developing countries, particularly in Sub-Saharan African cities, more than 65% of households use septic tanks or similar systems to treat their wastewater [5]. The pre-treatment of wastewater in a septic system is obtained by the settling of solid particles and the digestion of the settled and floated organic matter [6, 7]. The biomass activity in such reactors or in collective treatment plants depends on the chemical characteristics of the incoming flows [8].

Generally, domestic wastewater are classified into two major groups according to their origins [7, 9]: (i) grey waters corresponding to the wastewater coming from showers, laundries and kitchen, and (ii) black waters which are related to wastewater from toilets (containing faeces, urine and toilet papers). The chemical compounds in domestic wastewater are thus diversified and complex [10]. Several studies have been carried out to characterize the black and grey waters, but only few parameters have been studied [4, 9, 11-20]. These studies included the quantification per capita and per day of laundry detergents, shower soaps and shampoo in grey waters [9, 11, 13, 21], the characterization of conventional pollution parameters in black and grey waters [i.e., chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), total nitrogen, total phosphorus, total coliforms, fecal coliforms] [12, 14-16], the characterization of chemical compounds in faeces and urine (e.g., total nitrogen, total phosphorus, potassium, urea, NH_4-N, Mg^{++}, Ca^{++} and Cl^-)[17, 18, 20]. For example, Gray [22] and Mann [23] showed that in the United Kingdom wastewater from toilets, showers, kitchen sinks, laundries and car washing/garden represented 35%, 25%, 20%, 15%, and 5% volume/volume (v/v), respectively, of all domestic wastewater. Ucisik and Henze [24] found that in Denmark and Sweden wastewater from kitchen sinks and toilets (faeces and urine) are 18 and 19 m^3/capita/year, respectively. Their estimates of the total wastewater from both laundries and showers resulted in 18 m^3/capita/year in these countries. The results obtained through the numerous studies were noticeably different between authors. These differences could be linked to the various study sites (countries) which present different life style and nutrition habit of the people as well as the methodologies used.

Furthermore, there is a lack of detailed information (Table 1) on chemical compounds such as carbohydrates, lipids, proteins and conventional pollution parameters for different sources of domestic wastewaters (i.e., total infinite BOD_{ATU}, soluble and particulate COD). Yet such information is crucial for an accurate modelling approach of biochemical processes occurring in collective treatment plants or septic tanks in case of on-site sanitation.

The concept of the population equivalent is defined as the pollutant load rejected per capita and per day (expressed in form of various main chemical compounds associated to this pollution). It enables the determination of the overall pollutant load from various houses connected to a collective treatment plant. The main objectives of this study were (i) to characterize more thoroughly the generated fluxes by one population equivalent unit and their links to the conventional pollution indicator (i.e., COD), and (ii) to provide therefore the key different compounds which constitute a database useful (reliable inputs) for determining case by case the formula of a "complex substrate biomole" which represents the domestic wastewater in various conditions. Such formula is valuable for the mathematical modelling of biochemical processes occurring in wastewater treatment bioreactors (i.e. a new study which could be done taking into account results of this article).

Table 1: **Literature review of studies dealing with the characterization of human faeces and urine.**

Parameter	Human faeces (only)	Human urine (only)	Human faeces and urine (taken together)
Total nitrogen	2-3.5 g N/capita/day [a] 1.2-4.2 g N/capita/day [b] 1.75-4.9 g N/capita/day [c]	6.85-11.78 g N/capita/day [d] 7.5-9.5 g N/capita/day [a] 6.6-8.4 g N/capita/day [e] 7.5-13.3 g N/capita/day [c] 8 g N/l [f] 9 g N/l [g] 1.8-17.5 g N/l [h] 2.4-3.1 g N/l [i] 8.36g N/l [j]	9.9-13.2 g N/capita/day [a] 7.6-7.9 g N/capita/day [l] 10.1 g N/capita/day [m] 10 g N/capita/day [b]
Kjeldhal nitrogen	17.82 g N/kg dry weight of faeces [n]	5.29 g N/l [n]	
NH_4^+-N		2.3-2.9 g N/l [i] 8.57g N/l [j]	
TOC	14-38.5 g C/capita/day [c]	5.5-11.9 g C/capita/day [c]	
Raw COD	567.43gCOD/kg dry weight of faeces [n]	12.79 g COD/l [n] 4-11 g COD/l [h] 8.15 g COD/l [k]	
Ca^{++}	1.4-3.5 g/capita/day [c]	0.13 g/l [k]	1.5-2.1 g/capita/day [l]
Mg^{++}		1.5-1.63 mg/l [d]	0.25-0.4 g/capita/day [l]

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Creatinine		1.02 ± 0.15 g/capita/day [o] 1.2-2.1g/l [p]	
Uric acid		0.154-0.77 g/l [q]	
Urea		5.82-10.00 g N/capita/day [d] 5.81 g N/l [k]	
K^+	0.4-1.8 g K/capita/day [c]	33.31± 10.57 mEq/capita/day [o] 1.5-3.15 g/capita/day [c] 0.7-3.3 g/l [h] 2.00 g/l [j] 2.17 g/l [k]	1.8-2.7 g/capita/day [l] 3.29 g/capita/day [r] 4.0 g/capita/day [s]
Na^+		101.93 ± 35.30 mEq/capita/day [o] 2.67 g/l [k]	
Cl^-		3.03 g/l [j] 3.83 g/l [k]	
Total phosphorus	1.05-3.78 g P/capita/day [c] 0.3-2.7 g P/capita/day [a, e]	0.8-1.4 g P/capita/day [a, e] 1.25-3.5 g P/capita/day [c] 0.2-3.7 g P/l [h] 0.15-2.3 g P/l [i] 2.03g P/l [j]	1.8-3.7 g P/capita/day [l] 1.64 g P/capita/day [r]

References:

a:Heinss, Larmie [25]; **b:** GHD [26] cited by Montangero and Belevi [27]**; c:** Gotaas [28] cited by Mara and Horan [29]; **d:** Kirchmann and Pettersson [30]; **e:** Polprasert [31]; **f:** Ban and Dave [32]; **g:** Winker, Vinnerås [20]; **h:** Meinzinger and Oldenburg [33]; **i:**Heinonen-Tanski, Sjöblom [17]; **j:** Pradhan, Holopainen [19]; **k:** Udert, Larsen [34]; **l:** Schouw, Danteravanich [35]; **m:** Jönsson, A. [36]; **n:** Chaggu, Sanders [37]; **o:** Lee Watson and Langford [38]; **p:** de Araújo, Salles [39]; **q**: Hudaria, Duartea [40]; **r:** Wolgast [41] cited by Heinonen-Tanski and van Wijk-Sijbesma [18]; **S**:Verbanck, Vanderborght [42]

2. MATERIAL AND METHODS

A novel methodological approach combining the techniques described in following sections was used in data collection and allowed to correctly estimating the pollutant load in a household wastewater for one population equivalent unit. In other words, data collection was carried out through two complementary investigations in Burundi and Belgium. The study focused on the typical main pollution sources in a wastewater: faeces, urine, and toilet papers in black waters, and soaps, laundry detergents, and macronutrients (carbohydrates, lipids and proteins) as well as dishwasher detergents in grey waters from showers/bathtubs, laundries, and kitchen sinks, respectively.

2.1 Characterization of faeces and urine samples (experiments in Belgium)

Experiments in Belgium were focused on the chemical characterization of urine and faeces for quantifying their respective contributions in black waters. Measurements were carried out on 30 faeces and 49 urine samples collected in two Belgian hospitals on healthy persons (i.e., no suffering from any particular pathology). In order to get the characteristics of faeces and urine with minima error values, the persons were randomly selected but variation in age and gender was considered. Three age groups were taken into account (16 to 20, 20 to 40 and 40 to 70 years old) in the choice of those persons who provided the faeces and urine samples. Male and female as a gender were taken into account in the choice of those persons (proportion of 50/50) either for faeces or urine samples. Thus, faeces and urine produced during 24 hours were collected in order to determine (i) the quantities of faeces and urine produced per capita and per day, respectively, and (ii) the concentrations of chemical compounds (expressed in g/g of dry weight for the faeces and g/l for the urine) along with their corresponding pollutant loads. The parameters measured on aliquots of faeces and urine samples (obtained through a systematic sampling) were: raw COD and BOD_5, total infinite BOD_{ATU}, total organic carbon (TOC), nitrogen (total, organic and Kjeldahl), proteins, total phosphorus, ammonia nitrogen (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N), Cl^-, Ca^{++}, and Mg^{++}. Each parameter was expressed per its measurement unit, according to the population equivalent concept (e.g., g COD/capita/24h). In addition, the quantities of lipids, carbohydrates, soluble and particulate COD, and SO_4^{2-} were assessed in faeces samples; quantities of creatinine, uric acid, urea, K^+ and Na^+ were determined in urine samples.

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The fresh weights and volumes of the 24-hour samples were measured prior to the laboratory analyses. The aliquots were dried in an oven at 105°C during 24h. Then, they were weighted using an analytical balance (Sartorius® balance, France; accuracy ± 0.1 mg).

2.1.1 Measurements of the different compounds

Carbohydrates were measured using the anthrone method [43, 44]. The raw and soluble COD were measured on raw and filtered samples (GF/C filters), respectively, through the colorimetric method (ISO 15705; tubes series: 1 14691 0001). In this colorimetric method, a mineralizator (Spectroquant® TR420, Merck, Belgium) was used for the mineralization and a photometer (Spectroquant®NOVA60, Merck, Belgium) for the reading. Particulate COD was then calculated as the difference between raw and soluble COD.

The measurements of BOD_5 and total infinite BOD_{ATU} were carried out on unfiltered seeded samples using OxiTop® systems (WTW, Germany). The total infinite BOD_{ATU} was determined using the Thomas' method [45, 46] with samples being incubated in dark and under stirring for a 21-day period. Based on this method, the total infinite BOD is calculated as:

$$\text{Total infinite } BOD = \frac{1}{1 - 10^{-kt}} BOD_t \quad (1)$$

where BOD_t refers to the BOD measured at time t, t being the reaction time from the beginning of the test (expressed in days); k is the kinetic constant of reaction (expressed in base 10). A nitrification inhibitor (i.e., ATU (allylthiourea) 2g/l) was added in case of BOD_{ATU} determination.

Total nitrogen and TOC were measured on filtered samples (GF/C filter) with a Shimadzu analyzer (Shimadzu TOC, VCPH model). Organic nitrogen was calculated as a difference between Kjeldahl and ammonia nitrogen. The measurement of lipids in faeces samples was achieved using the infrared method [47]. Proteins in faeces samples were quantified by dosing Kjeldahl nitrogen (ISO 5663), according to the assumption described in previous studies (the N content in proteins is 16% weight/weight (w/w)); [48-50]. A 6.25 multiplicative factor was therefore used to convert Kjeldahl nitrogen content into proteins [50, 51].

The ion chromatography (Metrohm 883 Basic IC plus + Metrohm 863 Compact IC Autosampler) was used for the main cations (NH_4^+-N, Ca^{++}, Mg^{++}) and anions (NO_2^--N, NO_3^--N, Cl^-, PO_4^{3-}-P, SO_4^{2-}) on filtered samples (filters of 0.2 µm diameter). Note the quantities of NO_2^--N and NO_3^--N were below the detection limit.

For urine samples, the analyses were performed using a Unicel®DxC 800 Synchron LX®20 Clinical Systems analyzer (Beckman Coulter, USA). The methods used for the determination of each compound were [52]: the pyrogallol red-molybdate method for the urinary proteins, the Jaffe rate method for the creatinine, the enzymatic methods involving uricase and peroxidase, for uric acid, or involving urease and glutamate dehydrogenase for urea; and the indirect potentiometric method using specific electrodes for Na^+ and K^+ quantifications.

2.1.2 Determination of the theoretical chemical oxygen demand (COD) and total organic carbon (TOC)

As faeces and urine could contain other compounds that contribute to the COD and TOC, a theoretical approach of determination of these ones is necessary in order to validate the measured characteristics in faeces and urine samples. In the framework of verification if all compounds that have positive responses on the COD and TOC test were measured, the measured COD and TOC in urine and faeces samples (from the experiment in Belgium) were compared to those of theoretical calculated on all found compounds. Regression models corresponding to these comparisons between measured and theoretical TOC and COD in urine and faeces samples gives interesting informations which allow to understand if yes or no all compounds responsible of pollution have been measured.

For the theoretical TOC, it was calculated as the sum of the TOC of identified compounds in samples. In other words, theoretical TOC is calculated on compounds which have carbons in their chemical structures. Thus, for 1 g of a given compound, the equivalent TOC ($i_{TOC,\ compound}$) is calculated as follows:

$$i_{TOC,compound} = \frac{\text{Number of carbon atoms} * \text{Atomic mass of Carbon}}{\text{Molecular weight of compound}} \quad (2)$$

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Carbohydrates, lipids and proteins were represented by glucose ($C_6H_{12}O_6$), glycerol tripalmitate ($C_{51}H_{98}O_6$) [53], and alanine ($C_3H_7NO_2$), respectively. The choice of the alanine compound for representing proteins was guided by its relative abundance in animal proteins [54, 55] and plant proteins [56].

When the $i_{TOC,\ compound}$ and mass of a given compound are known (in faeces and urine samples), its theoretical TOC ($TOC_{compound(i)}$) is calculated using the equation (3) below:

$$TOC_{Compound(i)} = i_{TOC,compound} * Total \quad mass \quad of \quad compound \quad i \qquad (3)$$

For the theoretical COD, it was calculated as the sum of the COD of identified compounds in samples. It means that theoretical COD values were calculated for the three compounds in case of faeces samples (glucose, glycerol tripalmitate and alanine), as well as for urinary proteins, creatinine, uric acid and chlorides (Cl^-) in case of urine samples. For the chlorides, it is important to note that concentration which was taken into account is that was higher than a threshold of 2.50 g/l because under this concentration, the COD kits used for analysis contained $HgSO_4$ which eliminates the effects of chlorides interferences. In other words, theoretical COD for a given compound ($COD_{compound(i)}$) in faeces and urine samples was calculated using equation (4):

$$COD_{compound(i)} = i_{COD,compound} * Total \quad mass \quad of \quad compound(i) \qquad (4)$$

where $i_{COD,\ compound}$ denotes the amount of O_2 needed to oxidize 1 g of a compound and which is determined for each compound from its oxidation equation (5-10) and exploiting the equation (11):

Chloride: $2Cl^- \rightarrow Cl_2 + 2e^-$ (5)

Creatinine: $C_4H_7ON_3 + 7H_2O \rightarrow 4CO_2 + 3NH_3 + 12H^+ + 12e^-$ (6)

Uric acid: $C_5H_4N_4O_3 + 7H_2O \rightarrow 5CO_2 + 4NH_3 + 6H^+ + 6e^-$ (7)

Carbohydrates: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$ (8)

Lipids: $C_{51}H_{98}O_6 + 96H_2O \rightarrow 51CO_2 + 290H^+ + 290e^-$ (9)

Proteins: $C_3H_7NO_2 + 4H_2O \rightarrow 3CO_2 + 1NH_3 + 12H^+ + 12e^-$ (10)

In other words, these oxidation equations (5-10) above are the half-equations in which compounds are considered as electron donors. With this technique, it means that every compound that exchanges electrons during its oxidation has a positive response to the COD test and the equations (4 and 11) are used for calculation.

$$i_{COD} = \frac{8g\ O_2 * \text{number of electrons exchanged}}{\text{Molecular weight of the compound}} \qquad (11)$$

Where one electron exchanged corresponds to 8 gO_2 [57].

2.2 Characterization of toilet papers, laundry detergents, shower soaps and grey waters from the kitchen sinks (experiments in Belgium and Burundi)

The determination of the quantities of toilet papers and household chemical (shower soaps and laundry detergents) used per capita and per day, and their respective contributions in domestic wastewater were investigated in Belgium and Burundi. For this purpose, n = 60 households were surveyed in May 2011 in the city of Bujumbura (Burundi) using pre-established questionnaire and n = 60 households were also surveyed in December 2014 in the province of Luxembourg (Belgium) with the same pre-established questionnaire. Whereas in Belgium the surveyed households were selected in five different boroughs with a choice of twelve households per borough (random choice), in Bujumbura city they were selected in ten different districts with a choice of six households per district (random choice) Through the survey form (in Belgium or Burundi), each household provided information on the number of residents and the volumes/quantities used over the survey month for a given type of product "i"(i.e., toilet papers, shower soaps and laundry detergents). Thus, the number of persons surveyed per household in Burundi varied from

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four to seven, with a total of 337 individuals and varied from 2 to 3 in Belgium, with a total of 141 individuals. The quantity per capita and per day of each compound (toilet papers, shower soaps and laundry detergents) was deducted from the total weighed samples (i.e., depending on how the products are packaged). The sample aliquots of toilet papers, shower soaps and laundry detergents [dissolved in demineralized water for COD test and in mineral water for the BOD test (1 g/l)] were analyzed in order to determine the COD, BOD_5 and BOD_{10}. BOD_5 and BOD_{10} were measured on unfiltered seeded samples. The BOD_{10} was measured because of the slow biodegradation kinetic of toilet papers and detergents. The methods used for their determination were similar to that of Belgian samples (see Section 2.1). The grey waters from the kitchen sinks in those two countries (Burundi and Belgium) were also analyzed in order to understand their contribution in COD load per capita and per day. Grey waters from the kitchen sinks produced during 24 hours were therefore collected in order to determine volume produced per capita and per day and the associated COD, BOD_5 and BOD_{10}.

2.3 Characterization of faeces and urine by the Matter-Energy balance approach

Given the variation of pollution load per capita and per day (expressed in COD, nutrients, etc.) in domestic wastewater from one country to another (namely because of different life style and nutrition habit of the people that generate that pollution), the Matter-Energy balance approach is very useful for the determination of the pollution coming from faeces and urine per capita and per day, on a common basis.

In other words, this approach enables an accurate estimation of macronutrient quantities in black waters (i.e. faeces and urine taken together), for one population equivalent unit, if its balanced food ration (expressed as total chemical energy) is known. From all domestic wastewater produced by one population equivalent unit, this study assumes that the main difference comes especially from black waters rather than grey waters, though slight deviations could be observed among countries.

In this approach, a human body is considered as a biological reactor which receives inputs (expressed in form of balanced food rations) and generates outputs (faeces and urine), through the Matter-Energy balance and the metabolic activity (Figure 1). Based on the composition in macronutrients of a standard balanced food ration (expressed as percentage of energy), that to say 55%, 30% and 15% of carbohydrates, lipids and proteins, respectively [58-60], and the values from previous studies dealing with the energy needs (expressed as total chemical energy) per capita/day by age (i.e., 1500, 1800, 2000, 2120, 2239, 2500, 2600, 2800 and 3500 kcal/capita/day [59, 61, 62], the corresponding chemical energy of carbohydrates, lipids and proteins in these balanced food rations (considered as the inputs) were calculated. Most of these nutritional data were collected under Belgian conditions on vegetarian and omnivorous subjects [61]. The macronutrients in both faeces and urine samples (Belgian samples, Table 2) were considered as outputs and converted in form of chemical energy (in kcal/capita/day) using the COD concept. The conversion rates of these macronutrients were then deducted. According to this concept, 1 equivalent gram of electrons corresponds to 8 g COD [63] or 26.616 kcal [57].

Based on the values of macronutrients in the inputs and outputs of a human body (considered as a biological reactor), the conversion rates of carbohydrates, lipids and proteins were calculated as follows:

$$\eta = 100 * \left(\frac{S_0 - S}{S_0} \right) \qquad (12)$$

where η is the conversion rate (as percentage of energy); S_0 refers to the macronutrients involved in the balanced food rations (kcal/capita/day); and S refers to the outputs (i.e., macronutrients not used during the metabolism and eliminated in form of urine and faeces). Note the conversion rates used are valid for people with constant weight, i.e. the fractions of macronutrients stored are not taken into account.

When the conversion rates of the macronutrients are known, their respective percentage in the waste (faeces and urine taken together) can readily be calculated. Two techniques of calculation, based on the two paradigms prevailing in nutritionist and wastewater sciences, may be applied to determine the mass loads of the macronutrients. The principles of the paradigms rely on the equivalent energy of a liter of oxygen spent either for the metabolism or for wastewater treatment. According to the nutritionists' approach an equivalent energy of a liter of oxygen equals to 4.82 kcal/lO_2 [64, 65] (i.e., 26.99 kcal/g equivalent of electrons). While in wastewater treatment field, this corresponds to 4.75 kcal/lO_2 [57, 63]. For the nutritionists 1 g of carbohydrates, lipids, and proteins yields 4, 9 and 4 kcal, respectively [62]. Conversion rates (as percentage of energy) which appear on this illustration scheme (Fig 1) were calculated on basis of macronutrients (expressed in kcal/capita/day) themselves calculated from the nutrition data (i.e. balanced food rations of the persons who provided the faeces and urine samples - experiments in Belgium) and the macronutrients measured in faeces and urine samples (also expressed in kcal/capita/day) as well as the formula described by equation (12). Calculation of macronutrients in both faeces and urine samples (experiments in Belgium) using the COD concept approach was carried out by taking account the oxidation equations (8-10 and 11) and the converting factor (4.75 kcal/lO_2).

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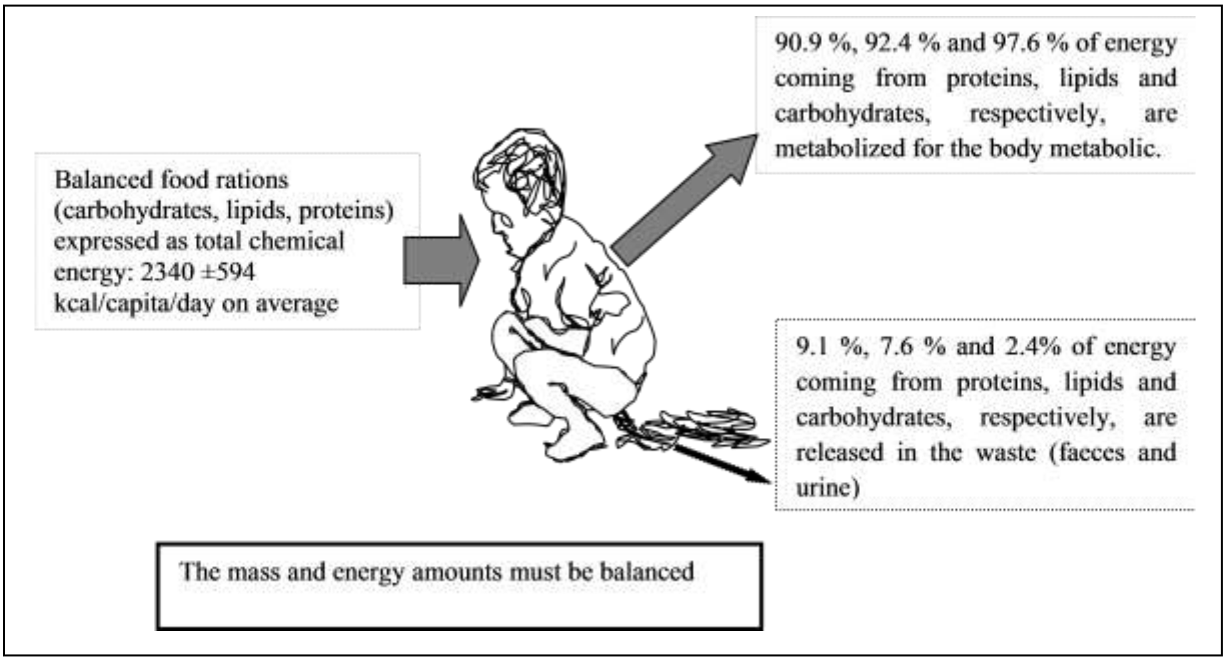

Figure 1: **Illustration scheme of a human body as a biological reactor. The conversion rates were determined in Section 3.3.**

2.4 Statistical analysis

For a given parameter or chemical compound, the pollutant load was calculated as the weighted average of all pollutant loads. For each sample "i", the corresponding pollutant load was determined as follows:

$$PL_i = C_i * W_i (\text{or } V_i) \quad (13)$$

where *PLi* refers to the pollutant load (in g pollution/capita/day; e.g. g COD/capita/day); C_i is the measured concentration (in 10^{-3}g pollution/g of dry weight of faeces or in g pollution/l of urine); W_i is the weight (in g faeces /capita/day), and V_i is the volume (liter/capita/day for the urine).

Likewise, for a given parameter or chemical compound the average concentration was calculated on all concentrations measured for all samples (faeces or urine).

The relationships between the theoretical and measured TOC and COD values were determined through correlation analyses. Statistical indicators, i.e., the coefficient of determination (R^2), the mean bias error (MBE), the root mean square error (RMSE) [66, 67] were used to assess the quality of these relationships. The RMSE and MBE are expressed as follows:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Y - Y_c)^2} \quad (14)$$

$$MBE = \frac{1}{n} \sum_{i=1}^{n} (Y - Y_c) \quad (15)$$

where Y and Y_c refer to the observed and predicted values, respectively; n is the number of samples.

All statistical analyses (preliminary checks and data processing, correlation analyses) were performed using Statistica® 10 (StatSoft Inc., Tulsa, OK, USA).

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3. RESULTS AND DISCUSSION

3.1 Characterization of faeces and urine samples (experiments in Belgium)

Table 2 presents the concentrations and pollutant loads of faeces and urine samples. The average fresh and dry weights of faeces samples were 225.79 ± 90.38 and 55.56 ± 17.92 g/capita/day, respectively. The average volume of urine samples was 1.58 ± 0.50 l/capita/day. The comparison of our results with those reviewed in Table 1 showed that they were quite similar, except TOC and COD values. The correlations between the measured and theoretical COD and TOC (Figure 2) were significant ($P < 0.05$). Overall, the R^2 varied from 0.92 to 0.98; the RMSE ranged from 0.16 to 0.26 g/capita/day, and 0.77 to 2.95 g/capita/day for the COD and TOC associated to the urine and faeces samples, respectively. The MBE was close to zero in all cases.

The correlations between the measured total and Kjeldahl nitrogen were also significantly high ($R^2 = 0.97$ and 0.99, $P < 0.05$, for faeces and urine samples, respectively). The comparison yielded a RMSE = 0.02 and 0.26 g/capita/day for faeces and urine samples, respectively, and a MBE = 0 g/capita/day for both types of samples. These results suggest that the total nitrogen was essentially composed of Kjeldahl nitrogen in our samples.

The sum of TOC in case of faeces samples included that of carbohydrates, lipids and proteins. In case of urine samples this sum included the TOC of creatinine, uric acid and urea in addition to urinary proteins. Thus, the theoretical TOC values were 0.40 g TOC/g protein, 0.76 g TOC/g lipid, 0.40 g TOC/g carbohydrate, 0.43 g TOC/g uric acid, 0.40 g TOC/g creatinine, and 0.20 g TOC/g urea. Based on the corresponding oxidation equation (Eq. 5-10), the COD of 1 g of each compound was 0.45 g COD/g chloride, 0.85 g COD/g creatinine, 0.29 g COD/g uric acid, 1.08g COD/g protein, 1.07g COD/g carbohydrate, and 2.88 g COD/g lipid.

Although urea was a significant compound in urine, its COD was zero (experimentally and theoretically proven through Eq. 16).

$$CO(NH_2)_2 + H_2O \rightarrow CO_2 + 2NH_3 + 0H^+ + 0e^- \quad (16)$$

The COD balance in the urine samples was completely balanced, indicating that the urine compounds responsible for the measured COD were creatinine, uric acid, urinary proteins and chlorides. Although a high correlation ($R^2 = 0.97$, $P < 0.05$) was found between the calculated and measured raw COD in the faeces samples, the observed regression ($y = 1.44x$) deviated from an ideal linear regression ($y = 1x$). This could be explained by the presence of bacteria, stercobilin and skatole in faeces [21], that unfortunately have not been measured in our study. However, Védry, Kuen [21] reported that stercobilin and skatole were present in trace amounts, while the bacterial content in faeces eliminated per capita and per day is 10^{11} cells [21] and corresponded to 10.5 g of dry weight/capita/day. According to Batstone, Keller [55], the bacteria formula is $C_5H_7O_2N$ and its "$i_{COD,\ compound}$" equals to 1.42 COD/g of bacteria. Accordingly, the total COD of bacteria was calculated and yielded 14.91 COD/capita/day. A new theoretical COD, determined as the sum of this COD and the theoretical COD calculated from identified compounds in faeces (Table 2), was 47.81±8.57 gCOD/capita/day (very close to the measured value, i.e. 47.54 ± 12.07 gCOD/capita/ day). This result suggests that faeces were constituted by the various compounds listed in Table 2 and bacteria, stercobilin and skatole in trace amounts.

Furthermore, our results showed that faeces samples contained high ratios of biodegradable organic matter. Indeed, the ratio raw COD/TOC (expressed in g COD/g TOC) was relatively high (4.00) in faeces samples, compared with the theoretical ratios of the methane (5.33), glucose (2.67) and pure carbon (2.67), determined using the Eqs. 17, 7 and 18, respectively. However, the ratio raw COD/TOC was 1.77 in urine samples, indicating that the organic matter was mainly in its oxidized form.

Methane: $$CH_4 + 2H_2O \rightarrow CO_2 + 8H^+ + 8e^- \quad (17)$$

Pure carbon: $$C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^- \quad (18)$$

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Table 2: **Average concentrations and pollutant loads of measured compounds in 24-hour human faeces and urine samples from the experiment in Belgium.**

Numbers in brackets refer to the standard deviation. Results are based on the population equivalent concept.

	Faeces		Urine	
Designation	**Concentration (mg/g of dry weight)**	**Pollutant load (g/capita/day)**	**Concentration (g/l)**	**Pollutant load (g/capita/day)**
Lipids	102.62 (35.13)	5.58 (1.96)		
Carbohydrates	154.48 (61.94)	8.71 (3.95)		
Proteins	132.58 (42.48)	6.95 (1.14)	1.36 (0.51)	1.96 (0.43)
Organic nitrogen	12.68 (5.11)	0.66 (0.16)	0.21 (0.07)	0.30 (0.07)
Total Nitrogen	22.91 (7.17)	1.20 (0.18)	5.49 (1.07)	8.58 (3.09)
Kjeldhal nitrogen	21.21 (6.79)	1.11 (0.18)	5.42 (1.05)	8.50 (3.11)
NH_4^+-N	8.53 (2.98)	0.45 (0.10)	5.21 (1.04)	8.20 (3.08)
Total phosphorus	48.19 (15.45)	2.55 (0.49)	0.90 (0.18)	1.40 (0.53)
TOC	214.71 (58.22)	11.67 (2.98)	2.10 (0.42)	3.24 (1.01)
Raw COD (measured)	873.97 (232.98)	47.54 (12.07)	3.82 (0.73)	5.75 (1.27)
Soluble COD	244.24 (65.04)	13.29 (3.38)		
Particulate COD	629.75 (167.94)	34.25 (8.69)		
Raw BOD_5	591.82 (158.87)	32.17 (8.15)	1.33 (0.23)	2.06 (0.66)
Total infinite BOD (with ATU)	796.97 (212.84)	43.36 (11.07)	2.98 (0.69)	4.46 (0.98)
Cl^-	2.47 (0.51)	0.14 (0.06)	3.64 (0.29)	5.70 (1.77)
SO_4^{2-}	22.56 (6.27)	1.30 (0.53)		
Ca^{++}	32.88 (11.14)	1.72 (0.31)	0.132 (0.02)	0.21 (0.08)
Mg^{++}	5.57 (1.26)	0.31 (0.08)	0.08 (0.01)	0.13 (0.04)
K^+			1.73 (0.43)	2.56 (0.47)
Creatinine			0.72 (0.24)	1.08 (0.34)
Uric acid			0.25 (0.16)	0.37 (0.18)
Urea			5.23 (1.04)	8.23 (3.08)
Na^+			2.44 (0.19)	3.86 (1.28)
Theoretical COD		32.90 (8.57)		5.71 (1.25)

The average fresh and dry weights of faeces samples were 225.79 ± 90.38 and 55.56 ± 17.92 g/capita/day, respectively. The average volume of urine samples was 1.58 ± 0.50 l/capita/day.

As a reminder, theoretical COD is calculated as the sum of the COD of identified compounds in samples.

The NO_2^--N and NO_3^--N are not shown as they were under the detection limit.

Figure 2 shows the comparison between measured and theoretical TOC and COD in urine (Fig.2 a) and faeces samples (Fig.2 b) from the experiment in Belgium.

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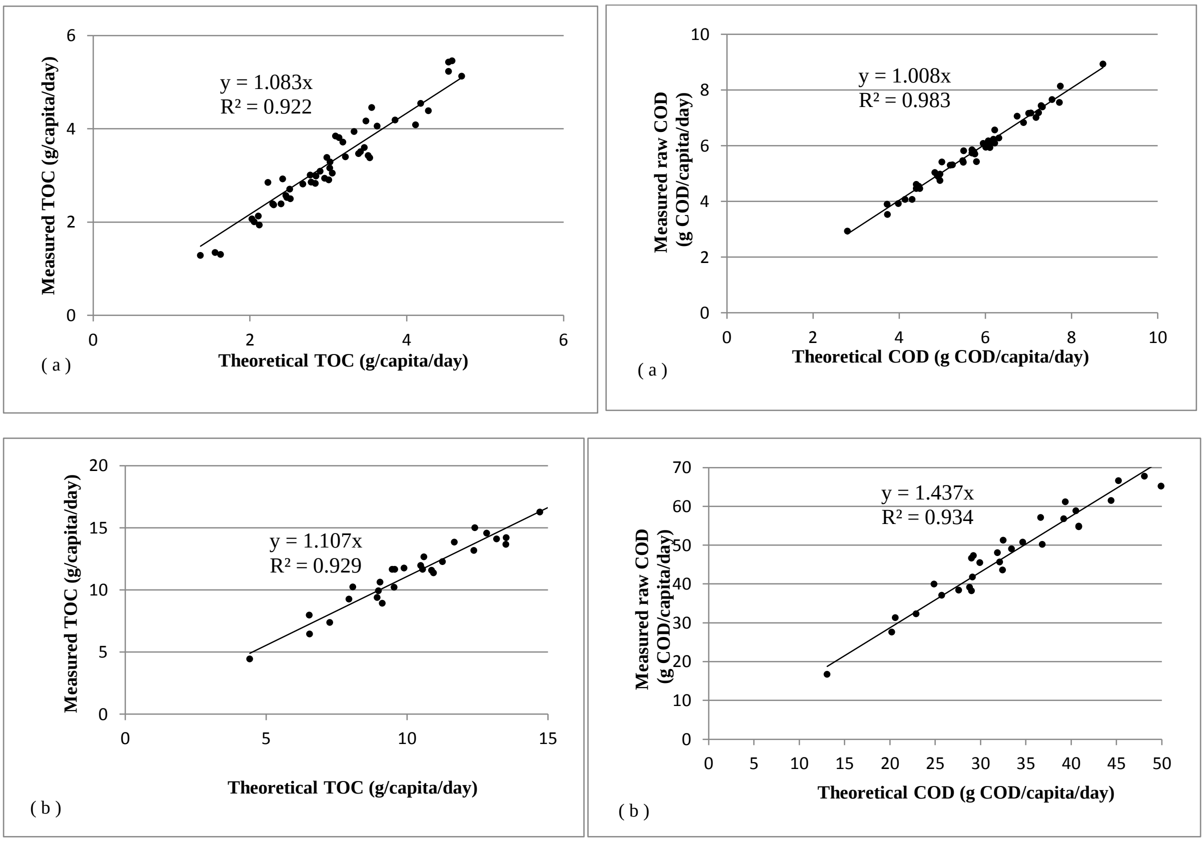

Figure 2: Comparison between measured and theoretical TOC and COD in urine (a) and faeces (b) samples from the experiment in Belgium.

In view of these linear regression models found (R^2 ranging between 0.922 and 0.983), (Figure 2), it is deductible that all compounds that having positive responses on the COD and TOC test in faeces and urine samples were all measured.

3.2 Characterization of toilet papers, laundry detergents, shower soaps and grey waters from the kitchen sinks (experiments in Belgium and Burundi)

The quantities per capita and per day of toilet papers, laundry detergents and shower soaps used in Bujumbura (Burundi) and province of Luxembourg (Belgium) were determined. The analyses showed that the amount of toilet papers used for one population equivalent unit were 12.20 ± 0.40 and 12.90 ± 1.42 g/capita/day in Burundi and Belgium, respectively. These results are close to those mentioned by Védry, Kuen [21] in the study conducted in France (12.00 g/capita/day). They do differ from the studies carried out in southern England (quantity = 19.40 g/capita/day [11] and in United Kingdom (quantity = 7.81 g/capita/day [13].

In our study the amount of laundry detergents used per capita and per day were 14.70 ± 0.40 and 17.75 ± 0.95 g/capita/day in Burundi and Belgium, respectively. This result found in Burundi is quite similar to those found in Finland, Norway and Sweden (14.00-15.00 g/capita/day),[9]. However, result found in Belgium is intermediate from those in Denmark (20.50 g/capita/day) and Sweden (15.00 g/capita/day). The quantities in Burundi and Belgium differed from those in Denmark and USA (20.50 and 10.00 g/capita/day, respectively [9].

Several varieties of shower/bath soaps were used. The total amount determined over the survey month was 5.00 ± 0,30 and 11.78 ± 0,57 g/capita/day in Burundi and Belgium, respectively.

Table 3 below shows the COD, BOD_5 and BOD_{10} associated to toilet papers, laundry detergent and shower soaps (experiments in Burundi and Belgium). Regarding the grey waters from the kitchen sinks, a volume of 27 ± 2.9 l/capita/day was found in Belgium with characteristics of 977 ± 23.07 mg COD/capita/day, 752 ± 19.2 mg BOD_5/capita/day and 910.91 ± 13 mg BOD_{10}/capita/day. Moreover, 18 ± 1.7 l/capita/day was obtained in Burundi with characteristics of 1310 ± 3.21 mg COD/capita/day, 1061 ± 7.12 mg BOD_5/capita/day and 1218 ± 1.3 mg BOD_{10}/capita/day. Therefore, the COD loads corresponding to the grey waters from the kitchen sinks were 26.38 ± 2.83 and 23.58 ± 2.23 gCOD/capita/day in Belgium and Burundi, respectively.

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Table 3: **Characteristics of toilet paper, laundry detergent and shower soaps in samples collected in Burundi and Belgium.** Raw BOD_5 and BOD_{10} were determined on solution containing 1 g of product by liter.

Designation	**COD (g COD/g of product "i")**	**raw BOD_5 (mg BOD_5/ g of product "i")**	**raw BOD_{10} (mg BOD_{10}/ g of product "i")**
Toilet paper (Burundi)	1.16 ± 0.03	410.00 ± 29.00	503.00 ± 33.00
Toilet paper (Belgium)	1.18 ± 0.05	436.00 ± 20.13	472 ± 17.20
Laundry detergent (trade mark "NOMI"),(Burundi)	1.25 ± 0.37	560.00 ± 21.00	623.00 ± 16.00
Laundry detergent (trade mark "DASH"), (Belgium)	1.27 ± 0.11	520.00 ±27.00….	596.00±23.20…
Shower soap (trade mark "Fa"),(Burundi)	1.77 ± 0.49	800.00 ± 50.00	1,100.00 ± 50.00
Shower soap (trade mark "EUBOS"),(Belgium)	1.81 ± 0.37	868 ± 37.40	.1160 ± 41.70

In view of these COD values, it appears that toilet papers were mainly composed of cellulose [measured COD close to the theoretical COD value of cellulose (1.185 g COD/ g cellulose)]. The comparison of the measured COD of laundry detergents and soaps with the theoretical COD of sodium lauryl sulfate (2.00g COD/g sodium lauryl sulfate) and sodium palmitate (2.88 g COD/g sodium palmitate), respectively, showed that our samples were composed of a mixture of various products. For one population equivalent unit in Burundi, the COD contributions of toilet papers, laundry detergents and shower soaps per capita and per day corresponded to 14.15 ± 0.9, 18.40 ± 6.09 and 8.85 ± 3.10 g COD, respectively. This COD contribution for each product was calculated taking into account not only the amount of this one but also its i_{COD} (itself expressed in g COD/g of product). In Belgium, the COD contributions of toilet papers, laundry detergents and shower soaps (and shampoo) per capita and per day corresponded to 15.22 ± 1.67, 22.54 ± 1.2 and 21.32 ± 1.04 gCOD/capita/day, respectively.

3.3 Characterization of faeces and urine through the Matter-Energy balance approach

The macronutrients contained in balanced food rations (considered as the inputs) were on average 1222.26 ± 566.05, 666.69 ± 308.76, and 333.34 ± 154.38 kcal/capita/day for the carbohydrates, lipids, and proteins, respectively. Considering the human body as a biological reactor, the average quantities of those compounds in faeces and urine (determined from Belgian experiments) were 31.00 ± 14.00, 53.44 ± 18.76 and 31.94 ± 5.59 kcal/capita/day for carbohydrates, proteins and lipids, respectively. Using equation (12) and these data, conversion rates (expressed as percentage of energy) equal to 97.6%, 90.9% and 92.4% were found for carbohydrates, lipids and proteins, respectively (conversion rates mentioned on Figure 1). It means that for the human body as a biological reactor, when a balanced food ration is consumed, 97.6% of carbohydrates, 92.4% of lipids, and 90.9% of proteins are metabolized for the body metabolic activity, while the remaining (i.e., 2.4%, 7.6%, and 9.1%, respectively) are released in the wastes (urine and faeces).

Regarding the measured quantities of macronutrients in the both faeces and urine samples collected in Belgium and those calculated using the two theoretical techniques (nutritionists' approach and COD concept approach), different deviations were observed, depending on the computation approach. Deviations from 8 to 11% (8% for lipids, 10 % for proteins and 11% for the carbohydrates) were found when the nutritionist approach was used. Whereas the deviations ranged from 0.22 to 0.39% (0.22% for lipids, 0.24 % for proteins and 0.39% for the carbohydrates) when the COD concept was used. Although both theoretical calculation techniques could be exploited to estimate macronutrients in human wastes (i.e., faeces and urine taken together), the technique based on the COD concept seems to be more accurate. Figure 3 below depicts the relationship between the amounts of macronutrients contained in faeces and urine (taken together) and balanced food rations consumed (expressed as total chemical energy).

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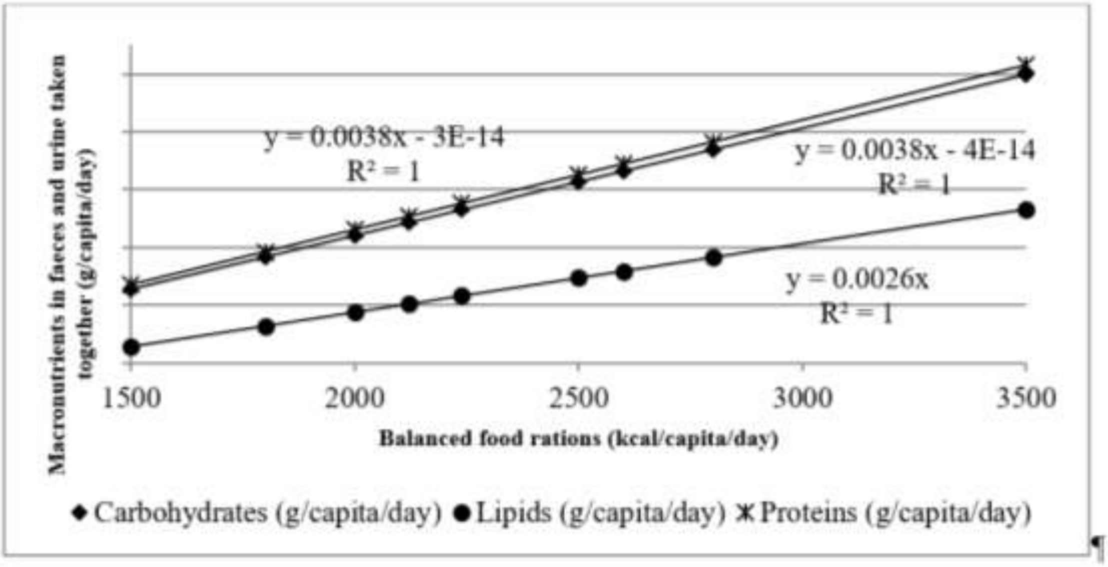

Figure 3: **Theoretical values of macronutrients in faeces and urine (expressed as total chemical energy, kcal/capita/day).**

These amounts of macronutrients in faeces and urine (Fig.3) were calculated using the COD concept. And the balanced food rations considered in this part of the study are those of taken from previous studies [59, 61, 62].

These regression equations found in this study are particular interest because they can serve as a basis for the determination of the macronutrients in black waters from faeces and urine if the average of balanced food ration consumed is known. The coefficient of determination found here ($R^2 = 1$) is due to the approach used which is theoretical although it combines experimental data and data from the previous studies. With these modelled data, this article provides an indication that COD load from excreta (faeces and urine taken together) can be estimated with a simple regression model based on the nutrition data from a person or group of persons. By modelling the human nutrient turnover, these relationships may be relatively universal for healthy persons and thereby applicable independent of life styles and cultural habits. These regression equations are only fit with this specific case of standard balanced food ration (ranging between 1500 and 3500 kcal/capita/day). For a broader application of this model (i.e. universal application), a further research could be needed to explore its effectiveness by using data collected from a broader group of persons living different geographical regions connected to different live-styles (local dietary data). For the moment, this article focuses on the Belgium and Burundi cases because the study was conducted in these two sites.

Regarding the black waters, the total COD corresponding to one population equivalent unit in Belgium and Burundi was determined taking also account these regression equations.

3.4 Synthesis of results in Belgium and Burundi

A synthesis was proposed for highlighting the results that could serve as a basis for the determination of the "complex substrate biomole" formula which represents all domestic wastewater.

Although the compounds such as carbohydrates, lipids and proteins were not measured in 24-hour samples of grey waters from kitchen sinks, they were estimated from their COD loads (26.38 ± 2.83 and 23.58 ± 2.23 gCOD/capita/day in Belgium and Burundi, respectively). Grey waters should reflect the same percentages (expressed in percentage of energy) than those of the compounds used (i.e. balanced food rations). Lavoie [58] indicated that the different percentages were 55, 30 and 15% for carbohydrates, lipids, and proteins, respectively. The calculations based on the COD concept resulted 13.56 ± 1.45 g carbohydrates/capita/day, 2.75 ± 0.29 g lipids/capita/day and 3.66 ±0.39 g proteins/capita/day for the case of Belgium. In Burundi, 12.12 ± 1.15 g carbohydrates/capita/day, 2.46 ± 0.23 g lipids/capita/day and 3.28 ± 0.31g proteins/capita/day were found.

The estimation of the amount of nitrogen content in such grey waters using the 16% w/w of nitrogen content in proteins [50, 51] resulted 0.59 ± 0.06 and 0.52 ± 0.05 g N/capita/day, respectively for Belgium and Burundi. This result does differ to that of Ucisik and Henze [24] who indicated that total nitrogen in waters from kitchen sinks was essentially in form of Kjeldahl nitrogen and was 0.30 kg N/capita/year (or 0.82 g N/capita/day). Tables 4 and 5 summarize the raw COD distribution and the total amounts of the main chemical compounds contained in studied grey and black waters, respectively, per capita and per day. The total COD and total amount of a given compound in all domestic wastewater were obtained by summing up the COD, or the amounts of the given compound found in the different types of grey and black waters. The experimental raw COD value obtained in Belgium

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experiments (138.75±20.09 g COD/capita/day) was similar to the results of Vasel [7] for the Belgium case (i.e., 135.00 g COD/capita/day). It did also fall in the range indicated by Ucisik and Henze [24] for numerous countries [105.00-200.00 g COD/capita/day, with an average of 150.00 g COD/capita/day)].

Although the COD corresponding to one population equivalent unit varies according to the standard of living by country, this study assumes that for grey waters there is not quite important difference from one country to another. Therefore, the COD of black waters can be estimated by exploiting the model linking nutritional data and COD load from excreta (faeces and urine taken together), (Figure 3) and Eq. 4, as well as the COD equivalent of 1 g of a given compound and their mass loads. For an average balanced food ration of 3500 Kcal/capita/day for Burundians, the total corresponding CODs representing all black 52.23 g COD/capita/day. Combining this result with those of other sources of pollution (experiments in Bujumbura), one population equivalent unit in terms of COD load which is 117.08 ± 10.09 g COD/capita/day.

Regarding the total nitrogen rejected per capita and per day (Table 6), 82.73% were produced in urine, 11.57% in faeces, and 5.70% in grey waters from kitchen sinks. The total nitrogen obtained in experiments in Belgium (10.37 ± 3.33 g N/capita/day) was in the range reported by Ucisik and Henze [24] (i.e., 8.00-16.44 g N/capita/day for populations in Brazil, Egypt, Turkey, Germany and Denmark). This result does differ from 19.2 g N/capita/day for populations in USA reported by Ucisik and Henze [24].

For the population equivalent of phosphorus (Table 6), faeces constituted an important source of phosphorus (57.82%), compared with the other pollution sources [urine (31.75%), grey waters from showers and laundries (6.12%) and grey waters from kitchen sinks (4.31%). The total phosphorus (4.41 ± 1.02 g P/capita/day) differed from the values reported by Ucisik and Henze [24] (values ranged from 1.10 to 3.28 g P/capita/day). This difference could be explained by the methodologies used and the study sites.

Regarding the specific potassium load, most of the results were derived from literature review because the analyses were performed only on urine samples. The pollutant load of potassium in the urine samples was 2.56 ± 0.47 g K/capita/day, and ranged in the same interval of reported results (Table 1). In wastewater from both kitchen and showers, and from laundries, one population equivalent unit produces 0.15 kg K/capita/year (or 0.41 g K/capita/day), respectively [24]. From the literature review, Gotaas [28] cited by Mara and Horan [29] found pollutant loads of potassium ranging from 0.40 to 1.80 g K/capita/day in faeces (black waters). A total pollutant load from these different pollution sources [urine samples, grey waters from kitchen and showers, grey waters from laundries [24], black waters (Gotaas [28] cited by Mara and Horan [29]) was therefore ranged from 4.04 to 5.44 g K/capita/day. A median value suggested by Ucisik and Henze [24] for one person was 4.38 g K/capita/day. The same value could also be considered in our study as the population equivalent of potassium.

Overall, our results showed that black waters contained an equivalent pollution of 49.37% of the raw COD generated by one population equivalent unit (percentage expressed as g COD/g COD); whereas grey waters contained 50.63% of the raw COD (Table 4, Figure 4).

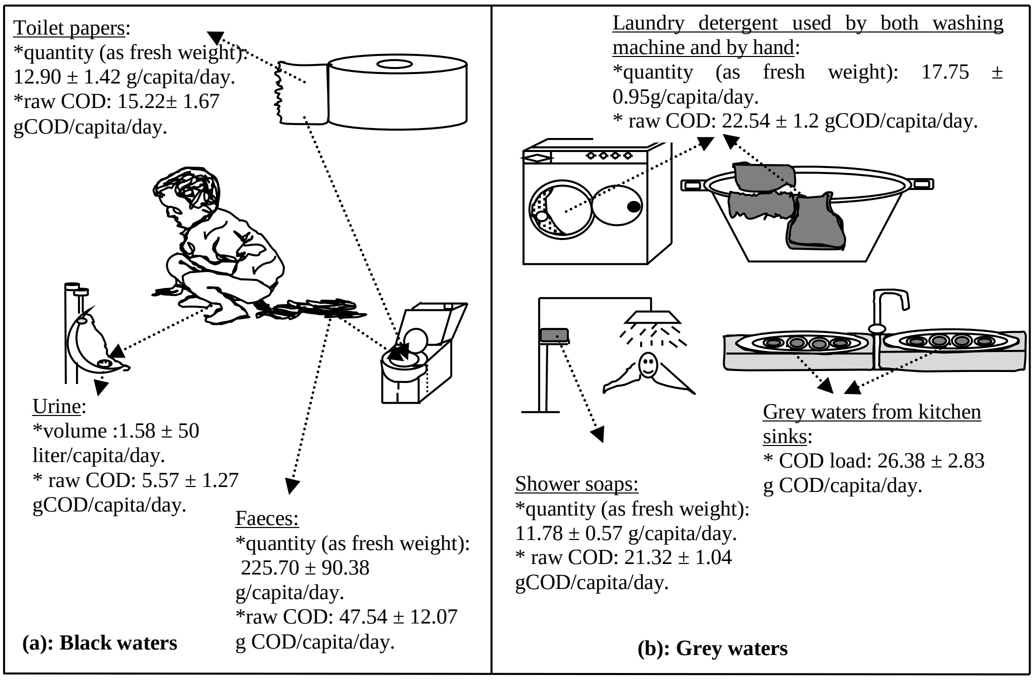

Figure 4: **Schematic synthesis of the content of black (a) and grey (b) waters generated per capita and per day (experiments in Belgium).**

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Black waters include faeces, urine and toilet papers from samples collected in Belgium/Burundi. Grey waters include shower soaps, laundry detergents and waters coming from kitchen sinks from samples collected in Burundi/ Belgium.

Table 4: **Distribution of the raw COD by pollution sources in studied grey and black waters in Belgium /Burundi.** The COD value of an unstudied source came from the literature. Results are based on the population equivalent concept.

Pollution source	Amount of pollution per source expressed as fresh weight (g /capita/day)	Amount of pollution per source expressed as COD (g COD/capita/day)	Percentage (%)	Source of data
Black waters				
Faeces (measured COD)	225.70 ± 90.38	47.54 ± 12.07	34.26	Belgium
Faeces (ΣCOD, calculated)[a]	225.70 ± 90.38	47.81 ± 8.75	-	-
Urine (measured COD)	1.58 ± 0.50[b]	5.75 ± 1.27	4.14	Belgium
Urine (ΣCOD, calculated)[c]	1.58 ± 0.50[b]	5.71 ± 1.25	-	-
Toilet papers	12.90 ± 1.42	15.22 ± 1.68	10.97	Belgium
Toilet papers	12.20 ± 0.40	14.15 ± 0.90	-	Burundi
Grey waters				
Laundry detergents	17.75 ± 0.95	22.54 ± 1.2	16.25	Belgium
Laundry detergents	14.70 ± 0.40	18.4 ± 6.09	-	Burundi
Shower soaps and shampoo	11.78 ± 0.57	21.32 ± 1.04	15.36	Belgium
Shower soaps	5.00 ± 0.30	8.85 ± 3.10	-	Burundi
Grey waters from kitchen sinks	-	26.38 ± 2.83	19.01	Belgium
Grey waters from kitchen sinks	-	23.58 ± 2.23	-	Burundi
Total (measured COD)	-	138.52 ± 23.43	100.00	Belgium
Total (calculated COD, by considering in faeces and urine samples, the identified compounds)	-	138.75 ± 20.09	-	Belgium

a: Sum of COD including the identified compounds in faeces samples which have a positive response to the COD test and bacterial content according to Védry *et al.* [21].

b: Volume of urine as liter/capita/day.

c: Sum of COD including the identified compounds in urine samples which have a positive response to the COD test.

a+c: The calculated COD from the both faeces and urine samples collected in Belgium.

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Table 5: **Amounts of the main chemical compounds in the both studied grey and black waters in Belgium.**

Total amount of a given compound "i" was obtained by summing up the amounts of the given compound found in the various sources of grey and black waters. Results are based on the population equivalent concept.

Chemical compounds	Amount (g/capita/day)	Source of data
Carbohydrates	35.17 ± 6.82	Belgium
Lipids	8.33 ± 2.25	Belgium
Proteins	12.27 ± 1.33	Belgium
Laundry detergents	17.75 ± 0.95	Belgium
Shower soaps and shampoo	11.78 ± 0.57	Belgium
Creatinine	1.08 ± 0.34	Belgium
Urinary amino acids	0.37 ± 0.18	Belgium
Total nitrogen	10.37 ± 3.33	Belgium
Total phosphorus	4.41 ± 1.02	Belgium

Table 6: **Distribution of total nitrogen and total phosphorus per pollution source in black and grey waters in Belgium**.

For unstudied parameters in some sources, results from the literature were taken into account (especially phosphorus in grey waters from kitchen sinks and grey waters from showers and laundries). The results are based on the population equivalent concept. The other pollution sources (i.e., toilet papers and grey waters coming from showers/bathtubs and laundries) do not contain nitrogen.

Pollution source	Total nitrogen (g N/capita/day)	Percentage (%)	Total phosphorus (g/capita/day)	Percentage (%)
Faeces	1.20 ± 0.18	11.57	2.55 ± 0.49	57.82
Urine	8.58 ± 3.09	82.73	1.40 ± 0.53	31.75
Grey waters from kitchen sinks	0.59 ± 0.06	5.70	0.19[a]	4.31
Grey waters from showers and laundries	-		0.27[b]	6.12
Total	10.37 ± 3.33	100	4.41 ± 1.02	100

a, b: Values from Henze *et al.* [24]

4. CONCLUSION

Complementary approaches (i.e., experimental and theoretical) were used (i) to thoroughly analyze the characteristics of grey and black waters samples (faeces, urine, soaps, laundry detergents, and kitchen sinks); and (ii) to redefine the population equivalent concept through a detailed basis. While the experimental results were valid for Burundi and Belgium, those derived from the theoretical approach were applicable to any country if the related nutrition data are known. In Burundi for e.g., precious results on toilet paper and household chemical consumption (laundry detergent and shower soap) were found per capita and per day: 14.15 ± 0.9, 18.40 ± 6.09 and 8.85 ± 3.10 g COD for the toilet papers, laundry detergents and shower soaps, respectively.

This article showed a strong relationship between nutrition data from a person or group of persons and COD load from excreta (faeces and urine taken together). A linear regression model found provides an indication that COD load from excreta (faeces and urine taken together) can be estimated with this model.

Different total chemical oxygen demands (COD) corresponding to one population equivalent unit in Burundi and Belgium were found by combining the two complementary approaches (i.e., 117.08 ± 10.09 g COD/capita/day and 138.75 ± 20.09 g COD/capita/day, respectively). Our results showed that the total COD depended of the life style and nutrition habit by country. Furthermore, in this study case the quantities of the main chemical compounds in grey and black waters, corresponding to one

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population equivalent unit, ranged from 0.37 ± 0.18 (for the urinary amino acids) to 35.17 ± 6.82 g/capita/day (for the carbohydrates), with specific values of 4.41 ± 1.02, 8.33 ± 2.25, 10.37 ± 3.33, and 12.27 ± 1.33 g /capita/day for the total phosphorus, lipids, total nitrogen and proteins, respectively.

Such results constitute valuable information for the determination of a "complex substrate biomole" formula, which is useful for the development of accurate stoichiometric and kinetic models of processes occurring in wastewater treatment bioreactors. These findings are currently exploited for developing accurate stoichiometric and kinetic models of the processes that occur in septic tanks for example. The process modeling approach in bioreactors (anaerobic or aerobic) using the "complex substrate biomole" formula can simplify the complexity of existing models (chemical compounds being usually taken separately in such models), and help in efficiently conducting laboratory analyses involving the control and management of bioreactors.

Our results could also be useful for the ecosanitation technology. Indeed, these results can be adapted to various conditions for assessing the corresponding loads if black waters are separated from grey waters or if urine are separated from faeces. They could also be useful for the other fields of interest which include the organic matter recovering for fertilization and/or methanation purposes and decision-making support, especially in developing countries.

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Corresponding Author: Nsavyimana Gaston, gaston.nsavyimana@ub.edu.bi

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