Greywater production in airports: Qualitative and quantitative assessment

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ABSTRACT

Airport complexes are great water consumers where the adoption of reuse practices adapted to their particular characteristics may represent significant savings of financial and environmental resources. Greywater reuse is an important alternative for reducing potable water consumption in airports. The objective of this study was to assess the quality of greywater produced in airport environments and the reuse potential of such effluent. This study was developed in a mid-size airport in Brazil, where a qualitative assessment of greywater produced by different activities was performed. The results were analyzed using descriptive and multivariate statistics. Greywater production in the administrative buildings was estimated by the application of questionnaires and interviewing employees, and compared to the non-potable demand in these buildings. The results showed that the quality of the greywater produced in the airport is similar to that produced in residences and can be easily treated for reuse purposes. In quantitative terms, greywater reuse can meet the non-potable demand and provide great savings of water and financial resources, in addition to priceless environmental benefits.

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1. Introduction

Great airport complexes worldwide consume water in the same proportion of small and mid-size cities. The Atlanta International Airport (Hartsfield-Jackson) presented, in 2009, water consumption equal to that of a city with a population of 13,000 people (HAIA, 2009). The London-Heathrow Airport consumed 1,852,000 m³ in 2010, which equals the consumption of a city of 25,000 people, and presented passenger traffic of 66 million people (LHA, 2010). The Narita International Airport, in Japan, with over 33 million passengers in 2010, presented in the same year water consumption equivalent to that of a city of 24,000 people (NIAC, 2010).

Great part of the water necessary to maintain airport infrastructure and operation routine is destined to non-potable activities such as air cooling systems, landscape irrigation, washing of aircraft, vehicles and runways, fire control testing, and toilet flushing. Considering this scenario, airports are potential environments for implementing processes and technologies aimed at the rational use of water such as greywater reuse.

Greywater consists of effluent from lavatories, showers, bathtubs, kitchen sinks and washing machines (Ottoson and Stenstrom, 2003; Liu et al., 2010; Nazer et al., 2010; Hernández Leal et al., 2011;

Hurlimann, 2011). Garland et al. (2004) and Lamine et al. (2007) state that the main factors which interfere in greywater quality are the supply water quality, the material used in the distribution system and the activities performed in a certain building or residence. According to Zhang et al. (2010) and Mourad et al. (2011) greywater is a suitable alternative water source for non-potable uses, such as toilet flushing, laundry and garden irrigation.

Regarding the quantitative aspects, the volume of greywater produced in residences and commercial or industrial activities varies according to local characteristics such as the number of employees, frequency of cleaning, existence of a dining hall, among others. These characteristics also vary according to the region, habits and purchasing power of the population. According to Al-Hamaiedeh and Bino (2010), 50–80% of the volume of effluent produced in a house is due to greywater.

The objective of this study was to assess and characterize the qualitative and quantitative aspects of greywater produced in an airport complex in order to infer about its reuse potential.

2. Methodology

2.1. Study area

The study was carried out in the Tancredo Neves International Airport (TNIA) located between 19°39' and 19°37' S and 43°59' and 43°57' W, in Confins, state of Minas Gerais, Brazil.

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According to the Brazilian Airport Infrastructure Enterprise (Infraero), the TNIA complex has an area of 15 km² and the capacity to transport over 10 million passengers every year. In 2011, the TNIA transported over 9.50 million passengers and consumed 259,470 m³ of water, which is 31% higher than the volume consumed in 2010 and makes it the fourth in the ranking of water consumption among all Brazilian airports (Infraero – personal communication).

The current context of high water consumption and expansion of the airport capacity justifies the development of this study since the greywater reuse potential can be considered in the planning of water resources management practices in the airport complex.

2.2. Greywater qualitative characterization

In order to assess the quality of greywater from different sources, samples from bathroom sinks, kitchen sinks and showers located in several areas of the TNIA were individually analyzed.

The sampling points where water was collected from bathroom sinks (Points 1, 2, 3 and 4) were chosen in order to represent the characteristics of the TNIA buildings including those with a fixed number of employees, those with floating population and with different hierarchy levels. With respect to the kitchen sinks, two sampling points were selected: one sink used for washing fruit and vegetables (Point 5) and one for washing dishes and kitchenware (Point 6). Samples from showers (Point 7) were collected in the locker room used by the employees of the maintenance company outsourced by Infraero.

The sampling campaigns were carried out from September 2010 to May 2011. Plastic siphons were adapted to the existing hydraulic facilities in order to divert the effluent to 50 L recipients. After each sampling campaign, the effluent was homogenized and laboratory samples were collected and conserved at 4 °C.

The analyses were performed according to recommendations of the Standard Methods for the Examination of Water and Wastewater – 21st edition 2005 (APHA, 2005), and the number of the procedure is indicated in parenthesis. The physical, chemical and microbiological variables analyzed were pH (4500-H⁺ B), turbidity (2130B), temperature (2550B), total suspended solids (TSS) (2540D), total solids (TS) (2540 B), total alkalinity (Alk) (2320B), total hardness (2340C), electrical conductivity (EC) (2510A), biochemical oxygen demand (BOD) (5220B), chemical oxygen demand (COD) (5220D), dissolved oxygen (DO) (4500-OG), nitrate (NO₃⁻) (4500-NO3E), ammonia nitrogen (NH₄⁺) (4500-NH₃C), total kjeldahl nitrogen (TKN) (4500-Norg C), total phosphorus (TP) (4500-PA), oils and grease (5520 A) and *Escherichia coli* (*E. coli*) (Colilert®).

2.2.1. Statistical analyses

Descriptive statistics (mean and standard deviation) were obtained using the software Microsoft® Excel 2010. In addition, two multivariate statistical analyses were used: Principal Components Analysis (PCA) and Cluster Analysis. PCA is used to transform an original dataset of variables from a multidimensional space into a more concise equivalent set (Omo-Irabor et al., 2008). This technique consists of transforming the original variables into others, non-correlated, named principal components, which correspond to linear combinations of the original variables (Sarbu and Pop, 2005). This analysis was used with the objective of assessing the importance of each of the variables studied in the dynamics of the greywater quality produced in the airport complex.

The cluster analysis was used to detect similarities among the sampling points, separating them into groups according to these similar characteristics. This technique reveals the behavior of a dataset without making any prior assumptions in order to classify objects of the studied system into categories or groups, based

on their similarities (Panda et al., 2006). The cluster analysis was performed in order to assess similarities/patterns in the characteristics of greywater in the sampling points and thus acknowledge the aspects related to the production of this effluent in airport environments.

These analyses were performed using the software R®, version 2.10.1, developed by the R Foundation for Statistical (R Development core team, 2009). The multivariate statistical procedures used the packages “FactoMineR” for PCA and “Cluster” for cluster analysis.

2.3. Quantification of greywater production and non-potable demand

Greywater production and non-potable demand at the TNIA were estimated from the amount of water consumed in the buildings located in the airport. The methodology based on studies carried out by Proença and Ghisi (2005) and Ghisi and Ferreira (2007), led to an estimate of the volume consumed in each building by each of the activities performed. Contributions from kitchen sinks, showers, bathroom sinks and cleaning activities were added to obtain the total amount of water produced in each building. In order to estimate the non-potable demand, the volumes consumed by activities such as toilet flushing, cleaning and irrigation were added.

The survey was carried out in eight buildings: Internal Revenue Service (IRS), Cargo Terminal (CT), Fire Section (FS), Airspace Control (AC), Fuel Area (FA), Equipment Shelter (ES), RA Group restaurant (RA) and the Infraero Maintenance Building (MB).

The estimate of water consumption in each building was performed by identifying the consumption habits of the users and assessing the specific flow for each sanitary fixture. Consumption habits were investigated by requesting employees to fill out questionnaires and by interviewing those responsible for cleaning the buildings. The questions of both questionnaires and interviews were related to frequency, form and duration of sanitary fixtures utilization and cleaning activities.

The flows of kitchen sinks and external taps used for irrigation were obtained using the direct flow measurement method. The mean value among all taps tested was used to estimate the total volume of water consumed. For toilets equipped with sanitary flushing valves, the flow of 1.7 L s⁻¹ was adopted, which is the maximum flow recommended by NBR 5626 (ABNT, 1998). The flow adopted for showers was 0.34 L s⁻¹, as suggested by a research developed by the University of São Paulo and the sanitation company of the state of São Paulo – Sabesp, for showers between 15 and 20 mwc, which is the regular water pressure for most showers in the buildings (SABESP, 1996).

After obtaining responses to the questionnaires and the specific flows for the sanitary fixtures, the water consumption was calculated for each activity in each building. In order to estimate consumption in taps, showers, toilets and urinals, Eqs. (1)–(3) were used.

$$C_1 = N_1 TQ_1 \quad (\text{taps and showers}) \quad (1)$$

$$C_2 = N_2 Q_2 \quad (\text{toilets and urinals}) \quad (2)$$

$$C_3 = (C_1 + C_2) \cdot D \quad (3)$$

where C_1 : water consumption per user of taps/showers (liters/day); C_2 : water consumption per user of toilets/urinals (liters/day); C_3 : monthly water consumption for each employee (liters/month); N_1 : frequency of utilization (number of times/day); N_2 : frequency of utilization (number of flushes/day); $C_1 + C_2$: total daily consumption for each employee (liters/day); Q_1 : sanitary fixture flow

Table 1
Qualitative characterization results for greywater at TNIA.

	Bathroom sinks			Kitchen sinks			Showers
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7
<i>Physical variables</i>							
Turbidity (NTU)	16.4 ± 5.5	10.7 ± 5.1	11.7 ± 6.9	24.7 ± 9.6	64.1 ± 79.9	123.7 ± 158.7	26.1 ± 26.9
TSS (mg L ⁻¹)	105.2 ± 55.5	40.5 ± 37.3	40.5 ± 12.7	67.2 ± 14.6	155.6 ± 143.1	208.2 ± 67.6	99.9 ± 43.9
TS (mg L ⁻¹)	309.2 ± 107.4	226.2 ± 121.0	262.0 ± 109.9	266.4 ± 73.4	578.9 ± 355.5	763.1 ± 200.2	404.1 ± 90.9
<i>Chemical variables (nutrients)</i>							
TKN (mg L ⁻¹)	6.9 ± 10.1	4.5 ± 3.9	7.2 ± 9.6	8.5 ± 2.8	12.4 ± 18.3	9.3 ± 10.3	32.5 ± 12.7
N-NH ₄ ⁺ (mg L ⁻¹)	0.8 ± 0.8	0.9 ± 1.1	0.6 ± 0.8	4.2 ± 3.7	0.3 ± 0.4	0.5 ± 0.9	26.6 ± 14.1
NO ₃ ⁻ (mg L ⁻¹)	5.8 ± 6.9	3.0 ± 3.1	5.3 ± 3.5	7.8 ± 5.0	6.6 ± 8.2	11.0 ± 7.5	5.5 ± 6.1
TP (mg L ⁻¹)	1.4 ± 0.7	0.8 ± 0.5	0.7 ± 0.3	0.8 ± 0.5	3.2 ± 3.1	8.4 ± 3.5	2.4 ± 1.2
<i>Chemical variables (organic compounds)</i>							
BOD ₅ (mg L ⁻¹)	79.7 ± 35.6	49.6 ± 20.5	45.7 ± 19.8	95.2 ± 19.6	549.4 ± 507.6	613.0 ± 243.3	82.5 ± 90.7
COD (mg L ⁻¹)	123.5 ± 48.1	68.4 ± 73.4	97.6 ± 36.5	228.3 ± 51.2	558.9 ± 528.8	912.2 ± 169.3	159.0 ± 131.6
<i>Other chemical variables</i>							
pH	7.5 ± 0.4	7.4 ± 0.3	7.4 ± 0.4	7.4 ± 0.5	6.2 ± 1.4	6.6 ± 0.8	7.5 ± 0.3
EC (μS cm ⁻¹)	468.8 ± 63.5	424.1 ± 39.9	424.2 ± 48.9	489.4 ± 15.4	635.6 ± 542.7	499.9 ± 122.2	855.9 ± 263.2
Alk (mgCaCO ₃ L ⁻¹)	210.2 ± 58.4	202.4 ± 36.4	195.5 ± 46.2	216.4 ± 49.3	200.0 ± 147.1	208.9 ± 42.7	302.7 ± 53.2
Total hardness (mgCaCO ₃ L ⁻¹)	176.7 ± 30.0	160.7 ± 11.4	208.0 ± 45.3	-	185.3 ± 29.1	154.7 ± 7.6	171.0 ± 4.2
Chloride (mg L ⁻¹)	33.1 ± 27.7	18.9 ± 6.4	21.0 ± 13.8	19.6 ± 8.8	96.0 ± 183.8	33.9 ± 11.4	74.0 ± 38.2
Oils and grease (mg L ⁻¹)	21.1 ± 27.1	2.3 ± 5.2	3.1 ± 6.8	17.3 ± 14.3	54.9 ± 65.8	201.8 ± 127.1	34.3 ± 9.3
<i>Microbiological variables</i>							
<i>E. coli</i> ^a (MPN/100 mL)	3.17 × 10 ⁰	2.57 × 10 ⁰	2.43 × 10 ⁰	1.62 × 10 ¹	2.00 × 10 ²	6.71 × 10 ²	5.92 × 10 ²

^a Geometric mean values.

(liters/second); Q₂: sanitary fixture flow (liters/flush); T: duration of each utilization (seconds/time of use); D: number of workdays of the employee in a month (days/month).

Thus Eq. (3) represents the sum of the results obtained for Eqs. (1) and (2) and provides the result for monthly consumption. The volume of water used for cleaning was estimated using 10 L recipi-ents, since it is the usual cleaning procedure adopted for most of the buildings studied. The volume consumed in other activities was calculated according to the type of use by multiplying frequency and duration of each activity (as obtained from the questionnaires and interviews) by the volume consumed each time the activity is performed.

3. Results and discussion

3.1. Qualitative characterization of greywater produced in the TNIA

The results obtained by the qualitative characterization of the greywater produced in the TNIA are shown in Table 1. The discus-sion of the results was performed considering groups of variables in order to facilitate comprehension.

3.1.1. Physical variables (turbidity, total suspended solids and total solids)

TS concentrations, evidenced by turbidity and TSS values, were higher for kitchen effluent (points 5 and 6). In these points, TSS are mostly due to residual food removed during the process of sanitation or when cleaning kitchenware. Eriksson et al. (2002) assessed the quality of household greywater collected separately from sewage effluent, and found higher TS concentrations for the kitchen effluent. Such result was explained by the diversity of the particles found. For bathroom sinks and showers, where the main uses are hand washing, mouth cleaning and bathing, TSS can be originated from hair, tissue fiber and sand particles, which explains the lower TSS concentrations found in such points. In greywa-ter treatment and reuse projects, the importance of the TSS level is related to the possibility of obstruction of pipes that conduct the effluent to the treatment plant. Although solids concentration

in greywater is usually lower than that for sewage effluent, the problems regarding pipe obstruction cannot be neglected (Eriksson et al., 2002). Besides, TSS can negatively interfere in effluent dis-infection, since large particles shield pathogenic organisms from inactivation (Winward et al., 2008).

Another characteristic observed regarding the physical vari-ables was that different results were found for the same sampling point, as shown by the high standard deviation value. Although a standardized sampling schedule has been followed, the activities performed in each sampling point on the different sampling dates were diverse, and consequently led to the production of effluent with distinct characteristics. For instance, the type of food that is prepared or the activity performed by the employee before taking a shower are factors which can contribute to the presence of solids in the effluent.

Donner et al. (2010) gathered information from many studies and presented TSS values ranging from 7 to 207 mg L⁻¹ for bath-room sink effluent, and from 235 to 720 mg L⁻¹ for kitchen sink effluent. Holden and Ward (1999) studied greywater from bath-room sinks and found turbidity values ranging from 12 to 100 NTU. Gilboa and Friedler (2008) found turbidity values between 15 and 240 NTU for bathtub, shower and bathroom sink effluent. These studies also obtained a high standard deviation for physical vari-ables in their analysis, corroborating the results of the present study and reinforcing the information that local and personal habits directly influence the quality of the effluent produced.

3.1.2. Nutrients (NTK, N-NH₄⁺, NO₃⁻ and TP)

The TKN average concentrations for bathroom sink samples ranged from 4.48 to 8.48 mg L⁻¹, whereas for kitchen sinks these values were between 9.28 and 12.45 mg L⁻¹. As for N-NH₄⁺, con-centrations ranged from 0.57 to 4.18 mg L⁻¹ for bathroom sinks and 0.26 to 0.49 mg L⁻¹ for kitchen sinks. The difference between TKN and N-NH₄⁺ concentrations is explained by the presence of organic nitrogen, mostly due to food residue. Such values are lower than those usually found in untreated sewage effluent, where the main nitrogen source is urine. According to Otterpohl (2002), only 3% of the nitrogen found in domestic sewage is due to greywa-ter, whereas urine contributes with 87% and feces with 10%. In

greywater, the main source of nitrogen is food residue. However, for point 7 (where shower samples were collected), TKN and N-NH_4^+ values were higher than those found in other points, reaching 32.51 and 26.65 mg L^{-1} , respectively. This can be explained by the habit some users might have of urinating during the shower.

The mean nitrate values ranged from 2.96 to 7.84 mg L^{-1} for bathroom sinks, from 6.65 to 10.98 mg L^{-1} for kitchen sinks, and 5.54 mg L^{-1} for the shower effluent. Prathapar et al. (2005) studied greywater produced in residences in Oman and found nitrate values of 28.7 mg L^{-1} for shower effluent and 10.2 mg L^{-1} for bathroom sinks. Eriksson et al. (2009) state that nitrate, as well as N-NH_4^+ , are not used in toiletries and cleaning products. Thus the probable sources are urine or even human skin cells.

The TP mean concentrations ranged from 0.71 to 8.43 mg L^{-1} , and the lower values were found for bathroom sinks whereas the higher concentrations were observed in the kitchen effluent. The main sources of phosphorus in greywater are hygiene and cleaning products. Even though such products are used at all of the sampling points assessed in this study, their use is more significant in kitchen sinks, due to the more frequent use of detergent for washing kitchenware, which explains why higher TP concentrations were observed at such points. Hernández Leal et al. (2011), in a research developed in Holland with greywater from residences which included uses such as laundry and food preparation, found mean TP concentrations of 7.2 mg L^{-1} .

In general, greywater has lower nutrient concentrations when compared to domestic sewage, especially nitrogen, because its main source is urine, whereas the main sources of phosphorus are cleaning products. Nevertheless, the values obtained for greywater produced in the TNIA are within the ranges found for several other authors in the literature.

The low nutrient concentrations in greywater can interfere in the treatment system adopted. Al-Jayyousi (2003) states that the low nutrient concentration in this effluent can limit the efficiency of a biological treatment system. Hernández Leal et al. (2011) state that the nutrient deficit can compromise the development of an aerobic treatment, whereas an anaerobic process would not suffer such impact.

3.1.3. Organic matter (BOD_5 and COD)

Although greywater does not receive any contribution from toilet effluent, the organic matter concentrations found in some sampling points were similar or even higher than the values expected for domestic sewage. For kitchen sink effluent (points 5 and 6), the mean BOD_5 concentrations ranged from 569.40 to 613.00 mg L^{-1} , and the mean values for COD ranged from 558.86 to 912.19 mg L^{-1} . In these points, organic matter is originated from food residue, oils and grease, detergent and other cleaning products. Eriksson et al. (2002) state that one of the main contributions for COD in sewage effluent is the use of cleaning products such as detergents. Given the wide use of such products in kitchen sinks, this explains the high COD concentrations found in greywater.

In bathroom sinks and showers, the mean concentrations ranged from 45.68 to 95.18 mg L^{-1} for BOD_5 and from 68.39 to 228.32 mg L^{-1} for COD. The main sources in these points are body residue, hair and soap. The results show some important distinctions in the constituents of greywater from different sources with respect to organic matter. According to Eriksson et al. (2009), such distinction can be attributed to the amount and type of product which accounts for BOD_5 and COD concentrations in greywater. The simple act of washing hands or taking a shower will differently influence organic matter composition if compared to the effluent from kitchens that present high concentrations of food residue and detergents.

Hernández Leal et al. (2007) obtained a mean BOD_5 value of 215 mg L^{-1} for greywater produced in residences, and a mean COD

concentration of 425 mg L^{-1} , which are higher than the values found in the TNIA for bathroom sink effluent and lower than those for kitchen sinks. Shafran et al. (2005), in a study performed in Israel, obtained lower concentrations: 62 and 200 mg L^{-1} for BOD_5 and COD, respectively.

Greywater produced in the TNIA presented good biodegradability characteristics, with a COD/BOD ratio ranging from 1.02 to 2.4 depending on the sampling points, and can be efficiently treated by a biological system. Lamine et al. (2007) and Li et al. (2009) obtained similar results with COD/BOD ratios of 1.05 and 1.50, respectively. However, depending on the supply water source and end-uses in a certain location, greywater can present distinct characteristics regarding biodegradability. According to Al-Jayyousi (2003), the COD/BOD ratio in greywater can reach up to 4/1, which is considered an effluent with poorly biodegradable organic matter. This is likely to happen when great part of the COD comes from chemicals such as cleaning products and detergents, as pointed out by Winward et al. (2008), who found a COD/BOD ratio of 4.3/1 in a study performed in England.

In addition to information regarding effluent biodegradability, BOD and COD concentrations also indicate the risk of dissolved oxygen depletion. This is a relevant issue in cases when it is necessary to store effluent prior to its treatment. Dissolved oxygen consumption and anaerobic conditions can cause the production of sulfide by sulfate reduction and the consequent emission of unpleasant odors.

3.1.4. Other chemical quality variables

Other chemical variables such as pH, EC, total alkalinity, total hardness, chlorides and oils and grease were measured.

The pH values in greywater depend on the pH of the supply water and can be influenced by the water end-use. The sampling points presented values near 7.0 and small variations among the samples, according to the low standard deviation values.

Water quality variables related to dissolved solids, such as total alkalinity, hardness and EC, presented high concentrations. These values can be explained by the natural characteristics of the supply water in the TNIA. The airport is situated in a karstic region where the interaction between soil and groundwater is intense and the dissolution of rocks during water percolation gives it a high content of dissolved solids, resulting in high values of EC, total alkalinity and hardness. The mean EC values ranged from 424.13 to 635.65 $\mu\text{S cm}^{-1}$, and total alkalinity from 195.55 $\text{mgCaCO}_3 \text{ L}^{-1}$ to 302.73 $\text{mgCaCO}_3 \text{ L}^{-1}$. For both variables, significant differences among the sampling points were not observed.

With respect to total hardness, there is no evidence that this variable can cause sanitary problems, however, its monitoring is important due to its association with scaling processes in hot water pipes, boilers and heaters. The mean values ranged from 154.67 $\text{mgCaCO}_3 \text{ L}^{-1}$ to 208.00 $\text{mgCaCO}_3 \text{ L}^{-1}$, thus the TNIA supply water can be considered hard (hardness >50 $\text{mgCaCO}_3 \text{ L}^{-1}$).

The mean chloride values for bathroom sink effluent ranged from 18.85 to 33.06 mg L^{-1} . For the points where kitchen effluent was collected, the mean concentrations ranged from 33.92 to 95.98 mg L^{-1} . For the shower effluent, the mean value was 73.97 mg L^{-1} . The presence of chloride in greywater is mostly due to the dissolution of salts such as sodium chloride, which justifies the higher values found in the kitchen effluent.

Kitchen sinks also presented the highest concentrations for oils and grease among all the sampling points, with mean values reaching 54.92 mg L^{-1} for point 5 and 201.82 mg L^{-1} for point 6. In this type of effluent, oils and grease are originated during the preparation of food, and even from food residues mixed to the effluent. Lower values were observed for bathroom sinks and for the shower, between 2.32 and 34.27 mg L^{-1} . The sources for oils and grease in

Table 2
Coefficients for each variable in the three first principal components.

Variables	PC1	PC2	PC3
pH	−0.63	−0.01	0.61
Turb	0.67	0.08	0.33
EC	0.35	0.89	−0.04
Alk	0.13	0.85	0.21
COD	0.95	−0.10	0.18
BOD	0.86	−0.22	0.06
TS	0.80	−0.26	−0.22
TSS	0.74	−0.19	−0.29
Chloride	0.40	0.73	−0.09
TKN	0.25	0.79	−0.22
NO ₃ [−]	0.50	0.02	0.53
NH ₄ ⁺	−0.07	0.68	−0.12
TP	0.78	−0.03	0.21
<i>E. coli</i>	0.35	−0.20	−0.81
Oils and grease	0.78	−0.26	0.33
% of the variance explained	37.48	22.73	12.41
% Accumulated	37.48	60.21	72.62

these points are probably residues from the human body, which explains why lower concentrations were found when compared to those from kitchen sinks.

3.1.5. *Escherichia coli*

Although greywater does not present contribution from toilet effluent, which is the main source for most pathogens, the presence of *E. coli* was detected in the samples.

For bathroom sinks, washing hands after using the toilet represents the main source of such organisms. For kitchen sinks, the source of *E. coli* is the process of washing food which may present such organisms on its surface.

The effluent from bathroom sinks presented maximum *E. coli* concentration of 10¹ NMP/100 mL, whereas kitchen sinks reached values of 10⁴ NMP/100 mL. These values approach those found in Canberra Airport, Australia, of 10³ NMP/100 mL (Canberra Airport, 2009).

Other researchers also found significant concentrations of indicator organisms in greywater. Halalsheh et al. (2008) analyzed greywater produced in small rural villages in Jordan and found *E. coli* values of up to 10⁵ NMP/100 mL. Ottoson and Stenstrom (2003), in a study carried out in Stockholm, Sweden, obtained *E. coli* values of up to 10⁶ NMP/100 mL. The presence of indicator organisms in different concentrations in greywater allows us to affirm that population habits can directly interfere in such variable.

The results obtained in this research show that greywater produced in the TNIA meets reuse recommendations for some activities with respect to contamination indicator organisms, for instance the drip irrigation of ornamental plants (WHO, 2006), which is an activity performed at the TNIA. However, it is important to highlight that the presence of *E. coli*, even in low concentrations when compared to the domestic sewage, indicates the need of a disinfection step in the greywater treatment system in order to minimize microbiological contamination risks.

3.2. Multivariate statistics

3.2.1. Principal component analysis

The principal component analysis (PCA) was carried out in order to assess the behavior of water quality variables at the different sampling points (sources) and thus infer about the importance of each of them in the production dynamics of this effluent in the TNIA.

The results allowed us to reduce the 15 initial variables to 3 principal components which accounted for 72.62% of the total variance in the data. Table 2 presents the coefficients for each variable in the first 3 principal components. The boldface values are the highest coefficients obtained.

Fig. 1. Dendrogram resulting from the cluster analysis.

Principal component 1 explained 37.48% of the total variance, and the variables which most positively contributed to it were BOD and COD.

This component shows the importance of certain activities in the composition of greywater. The main sources of the variables with high coefficients are food residue and body residue from bathing and washing hands. Although all greywater sources evaluated in this study may contribute at some level to such variables, the descriptive statistical results show that the mean concentrations in the kitchen effluent were always higher than those for the other points. Thus it is possible to state that principal component 1 represents the relevance of the kitchen sink effluent in the quality of the greywater produced in the TNIA. If a greywater treatment and reuse system is to be implemented, such fact needs to be taken into consideration. The treatment system proposed should be able to receive the organic matter load and other pollutants from kitchen effluent in order to meet effluent reuse recommendations.

Principal component 2 explained 22.73% of the total variance and presented strong contribution by the variables electrical conductivity and total alkalinity. This component shows the importance of the quality of the supply water in greywater characteristics. The TNIA is supplied by groundwater and is situated in a karstic area. These are environments where the water resources present high levels of ions in solution from the dissolution of carbonate rocks. The results evidenced a close relationship between soil components and groundwater, as well as the importance of this relationship in the quality of the greywater produced in the airport.

Principal component 3 explained 12.41% of the total variance and presented strong contribution by the variable *E. coli*. This result represents the influence of fecal contamination on the quality of greywater produced in the TNIA. This statement allows us to infer that a disinfection process is necessary in order to minimize contamination risks in case of effluent reuse. Nevertheless, it is important to highlight that *E. coli* concentrations in greywater were lower than those usually found in domestic effluent and, depending on the intended use for treated greywater, *E. coli* values presented in Table 1 can be satisfactory.

3.2.2. Cluster analysis

The result of the cluster analysis is shown in Fig. 1, where three distinct groups can be observed.

Table 3Water consumption estimated for each activity in each building (m^3).

	IRS	FC	MB	AC	FA	ES	CT	RA
Toilets	34.6	23.3	31.0	50.2	23.3	71.3	53.9	31.5
Taps	26.2	42.5	42.4	78.5	53.5	122.9	63.6	26.1
Urinals	1.3	3.7	2.2	1.7	7.2	13.9	13.7	3.5
Showers	49.5	131.3	28.6	141.0	101.2	0.0	0.0	54.5
Cleaning	8.7	9.7	2.5	20	1.5	3.7	54.1	2.5
Irrigation	101.9	15.3	69	18.1	18.1	–	280	9.1
Other activities	2.7	2.6	–	–	7.6	–	–	9.1
Total	224.9	228.2	175.8	309.5	212.4	211.8	465.3	136.1
Sample error (%)	12.9	8.5	11	12.1	15	–	13.9	6.7

Group I consists of points 1, 2, 3 and 4, where bathroom sink effluent was collected. The effluent produced in these points presented lower values for most of the variables analyzed. The exceptions are electrical conductivity, total alkalinity and hardness, which are not strongly influenced by the type of activity and thus presented values similar to those observed in supply water.

Group II is formed by point 7 alone, where shower effluent was collected. This point is characterized by high values of TKN and N-NH_4^+ . According to Otterpohl (2002), since greywater do not receive toilet effluent contribution, they present lower concentrations of several fractions of nitrogen, and account for only 3% of the nitrogen concentration in domestic sewage. Thus we can assume such high TKN and N-NH_4^+ values are due to the habit of urinating during the shower.

Group III is composed by points 5 and 6, which represent kitchen sink effluent. These points are characterized by high concentrations of solids and organic matter (BOD_5 and COD), and present the highest values for many other variables such as nitrate, total phosphorus, chlorides and oils and grease, when compared to the other sampling points. Such characteristics were reflected on the separation of these points into a separate, which allows us to infer about the relevance of kitchen effluent on the quality of the greywater produced in the TNIA. The difference among the studied greywater sources was significant, and since kitchen effluent presented the highest concentrations for many of the analyzed variables, it is necessary to assess the possibility, or the necessity, of separating greywater from different sources in order to make reuse projects technically and economically feasible. Such information can be reinforced by Nolde (1999) and Otterpohl (2001), which do not classify kitchen effluent as greywater due to the high levels of organic matter.

3.3. Greywater production and non-potable water demand

The analysis of the responses to questionnaires applied to the employees of the studied buildings and the interviews carried out with those responsible for cleaning activities allowed us to identify the main water end-uses and those which are the greatest water consumers. Through this discretized survey, it was possible to estimate the greywater production, as well as the non-potable demand in the buildings at the TNIA.

Table 3 presents the monthly water consumption (m^3) of the activities performed in each building considered in the study, as well as the sample error assumed for each building. The sample error should be the lowest possible; however, for buildings with small populations, if low sample errors were used, samples tended to be the total population size. Thus we adopted the maximum sample error as 15% according to the number of questionnaires applied to each building. This value is within the recommendations by Barbetta (2003), who suggests a maximum error of 20%.

From consumption volumes estimated for showers, taps, cleaning and other activities, the total estimated volume of greywater

produced in each building was obtained. Toilet and urinal consumptions, as well as water used for irrigation and cleaning activities, were considered to estimate the non-potable water demand for each building in the TNIA. Fig. 2 presents the amount of greywater produced and the non-potable demand.

Fig. 2 shows that in the FC, AC, FA, ES and RA, greywater production is higher than the non-potable demand. At the IRS, MB and CT buildings, the demand overcomes production.

A common characteristic among the three highest greywater producers is the elevated shower consumption. At the FC, AC and FA, the water used in showers represented 57.5, 45.5 and 47.6% of the total volume consumed, respectively. Thus even though the showers are not used at all buildings in the TNIA, this is an important end-use for greywater production.

Another aspect was the high consumption by taps. Many employees affirmed that they use bathroom taps (sinks) for face rinsing and sometimes washing fruits for snacks or after lunch. But the main activities are hand washing and teeth brushing. The estimated duration for teeth brushing varied from 1 to 2 min with the tap open, at a frequency from 1 to 4 times a day. For hand washing, the frequency varied from 1 to 15 times a day.

The buildings which presented higher non-potable demands were CT and IRS. The common characteristic observed in these buildings was the high volume of water consumed for irrigation of the surrounding areas. From the total volume consumed in the IRS ($224.9 \text{ m}^3/\text{month}$), 45.3% is used for irrigation, whereas for the CT, from the total of 465.3 m^3 consumed every month, 60.1% are destined to irrigation. Toilet flushing was the non-potable activity with the second highest consumption. Different from irrigation, toilet flushing is a common use for all buildings studied. Fig. 3a and b presents respectively, the contribution (percentage) of each activity to the total volume of greywater produced, and the non-potable water demand.

Fig. 2. Greywater production and non-potable water demand for each building in the TNIA.

Fig. 3. (a) Percentage of each activity in greywater production. (b) Percentage of each activity in the non-potable water demand.

The results showed that considering all studied buildings, greywater production ($1,086.5 \text{ m}^3/\text{month}$) was higher than the non-potable water demand ($1,002.3 \text{ m}^3/\text{month}$). Thus the balance between the volume of water consumed in activities which can be performed with non-potable water, and the volume of greywater produced is positive. In other words, the total non-potable demand can be met by greywater. Although three buildings presented higher non-potable demands than the amount of greywater produced, such demand can be supplied by greywater produced in other buildings. The positive balance between greywater production and non-potable demand emphasizes the great potential for reuse of such effluent in airports. Moreira Neto et al. (2012) present activities which can be supplied by greywater such as the tests for fire control, air cooling systems, washing of vehicles, aircraft, besides runways and paved areas.

Greywater reuse in airports can provide great water savings, along with financial benefits and important positive environmental impacts. For the TNIA, specifically, where the main supply source is groundwater, reducing the volume of water collected from aquifers can contribute to maintaining the stability of this environmental system. According to Calijuri et al. (2012), the karstic aquifers are highly vulnerable to pollution and extremely susceptible to anthropic actions. From the results obtained in this study, greywater production in the TNIA is suitable and does not represent an obstacle to reuse of such effluent in the airport.

4. Conclusions

The qualitative analysis showed that greywater can present distinct characteristics depending on its source. Such differences were enhanced by the cluster analysis results, which separated into distinct groups the sampling points where greywater was produced by different activities.

The principal component analysis showed the importance of the kitchen effluent and the quality of the supply water for the final quality of greywater, and also highlighted the need for disinfection of such effluent prior to reuse.

The kitchen effluent, because of high levels of organic matter, may require a more sophisticated treatment and account for high costs to the reuse system. Thus it is necessary to assess the concentration of such variable and the volume of other types of effluent before deciding to treat kitchen sink effluent separately from effluent from other sources.

The importance of supply water was highlighted by the observation of high levels of total alkalinity and electrical conductivity

in greywater, which showed that regional characteristics that influence the quality of supply water must be assessed in the development of a project for greywater reuse.

The necessity of a disinfection step must be assessed, since even though the mean values for *E. coli* were within the concentrations required for many non-potable uses, the maximum values found reached 10^4 MPN/100 mL. Thus a disinfection process would minimize microbiological risks and increase safety for the users.

With respect to quantitative terms, important characteristics were identified, such as the activities with greatest greywater production (showers and sinks) and those which present the highest water demand (irrigation and toilet flushing). In addition, the quantification of the amount of greywater produced in the airport emphasized the great potential for water savings by means of reusing effluent. The positive balance between greywater production and water demand can provide financial savings and priceless environmental benefits.

Finally, qualitative and quantitative aspects addressed in this study proved that there are no significant limitations for implementing greywater reuse systems in airports, once this effluent can be treated by low-cost systems and the amount of greywater produced meets the demand of activities which can be supplied by reuse water. The results presented here corroborate the adoption of such practice for many non-potable uses by many airports worldwide, resulting in financial savings and environmental gains.

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