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CHEMICAL AND MICROBIAL CHARACTERIZATION OF HOUSEHOLD GRAYWATER

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ABSTRACT

In arid areas, the search for efficient methods to conserve water is of paramount importance. One of the methods of water conservation available today is graywater recycling – the reuse of water from the sinks, showers, washing machine, and dishwasher in a home. The purpose of this project was to characterize the chemical and microbial quality of graywater from a single-family home with two adults. Water samples from a graywater holding tank were analyzed over a seven-month period for total coliforms, fecal coliforms, fecal streptococci, *Staphylococcus aureus* (*S. aureus*), Pseudomonas aeruginosa (*P. aeruginosa*), and coliphages. The pH, turbidity, biological oxygen demand (BOD), suspended solids (SS), electrical conductivity (EC), sulfates (SO_4), and chlorides (Cl) were also measured. The mean numbers of total coliforms, fecal coliforms, fecal streptococci, and *P. aeruginosa* were 8.03×10^7, 5.63×10^5, 2.38×10^2, and 1.99×10^4 CFU/100 mL, respectively. *S. aureus* and coliphages were not detected. In the chemical analysis, mean values of 7.47 for pH, 43 nephelometric turbidity units (NTU) for turbidity, 64.85 mg/L for BOD, 35.09 mg/L for SS, 0.43 mS/cm for EC, 59.59 mg/L for SO_4, and 20.54 mg/L for Cl were measured. These data were compared to

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data taken in 1986 and 1987, when two adults and one child lived in the household. Analysis showed no statistically significant difference in levels of total coliforms and suspended solids between the two data sets. There were statistically significant differences in levels of fecal coliforms, pH, turbidity, chlorides, sulfates, and BOD between the two households. Fecal coliforms, turbidity, and BOD were higher in the household with two adults and one child. Levels of Cl, SO_4, and pH were higher in the household with two adults.

Key Words: Graywater; Wastewater; Coliforms.

INTRODUCTION

In arid regions of the U.S., water conservation and reuse are issues of great concern. Finding ways to reuse water is vital to the sustainability of the water supply and the future of these areas. Treating and reusing wastewater is one of the options communities in arid areas have. There have been many large scale reuse efforts, such as using treated municipal effluent to water golf courses or recharge groundwater (1). But the potential of wastewater reuse is not limited to large projects supplied by community wastewater treatment plants. It is also available to homeowners. Graywater recycling offers a way for people to reuse the wastewater from their own homes, especially homes not connected to municipal sewer systems.

Graywater is defined as all wastewaters generated in the household, excluding toilet wastes (2). It can come from the sinks, showers, tubs, or washing machine of a home. It has been reused for landscape irrigation and toilet flushing. Little data is available about the chemical and microbial quality of this water. Studies of graywater from a single family home have shown that it contains total and fecal coliforms and heterotrophic plate count (HPC) bacteria (2,3). If graywater is being reused for residential water conservation, then concerns about its safety need to be addressed, especially concerns about the potential for disease transmission. Homeowners may use graywater to irrigate ornamental and food plants, which is a concern because there is epidemiological evidence that the use of wastewater, particularly for the irrigation of food crops, has resulted in disease transmission when undisinfected effluent was used (4). To assess the risks of graywater use, more information about the quality of this water is needed. Therefore, the objectives of this study were: 1) to measure the chemical and microbial quality of graywater from a single family home of two adults, and 2) to compare these data with data taken from the same home several years earlier, when two adults and one child lived there.

METHODS

The graywater in this study came from the Casa del Agua, a single-family home in Tucson, Arizona. The house was retrofitted with a graywater recycling system (Figure 1) which provided water for outdoor irrigation. The drain system in the house brought the water from the washing machine, sinks, and showers to a collection sump, where it was pumped into a holding tank. The water then passed through a sand filter to an underground storage cistern. Water was pumped from the cistern to a subsurface irrigation system. At the time of the study there were two adults living in the home, which produced approximately 75 gallons of graywater per day.

Graywater samples (1-liter) were taken from the holding tank. They were collected in sterile bottles and transported on ice to the laboratory, where bacterial analysis was done within 4 hours of collection. Turbidity and pH were measured before bacterial analysis began. Additional analyses for biological oxygen demand (BOD_5), total suspended solids (TSS), electrical conductivity (EC), sulfates (SO_4), and chlorides (Cl) were also performed at the University of Arizona.

Total coliforms, fecal coliforms, fecal streptococci, and *Pseudomonas aeruginosa* were measured using spread plate and membrane filtration methods as described in *Standard Methods for the Examination of Water and Wastewater* (5). MEndo agar (Difco, Detroit, MI) was used for total coliforms, mFC agar (Difco) for fecal coliforms, and KF streptococcus agar (Difco) for fecal streptococci. Baird Parker agar (Difco) was used for *Staphylococcus aureus*, and presumptive *S. aureus* colonies were inoculated into coagulase plasma for confirmation. MPA medium was used for *P. aeruginosa*. Oxoid *Pseudomonas* agar was later substituted to improve recovery of *P. aeruginosa*. Coliphages were measured using the double layer agar method with *E. coli* strain ATCC #15597 as the host (6). Biological oxygen demand (BOD), sulfates (SO_4), chlorides (Cl), conductivity (EC), and total suspended solids (TSS) were measured according to the *Standard Methods for the Examination of Water and Wastewater*.

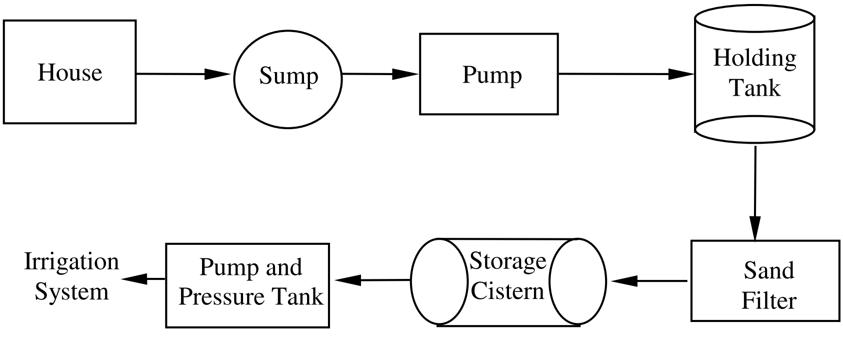

Figure 1. Graywater system at the Casa del Agua.

Statistical analysis was done using analysis of variance with Microsoft Excel 97 software (Microsoft Corp., 1997). The level of significance used was $\alpha = 0.01$.

RESULTS

Family of Two Adults

During the study period, October 1997 through April 1998, a total of 20 samples were collected. The chemical results are shown in Table 1.

The bacteriological results are shown in Table 2. Coliphages were less than 1 PFU/ml. *Staphylococcus aureus* was not detected in any of the samples. Fecal coliforms were present in all samples over a seven-month period.

Table 1. Chemical and Physical Characteristics of Graywater Produced by a Family of Two Adults

	Arithmetic mean	Geometric mean	Minimum value	Maximum value	Range
PH	7.47	7.46	6.87	8.15	1.29
Turbidity (NTU)	43.00	40.65	22.20	72.40	50.20
BOD (mg/L)	64.85	63.31	41.00	85.00	44.00
TSS (mg/L)	35.09	29.36	15.00	112.00	97.00
EC (mS/cm)	0.43	0.43	0.36	0.52	0.16
SO_4 (mg/L)	59.59	57.21	39.80	88.50	48.70
Cl (mg/L)	20.54	20.03	16.30	33.40	17.10

Table 2. Microbial Characteristics of Graywater Produced by a Family of Two Adults

	Arithmetic mean	Geometric mean	Minimum value	Maximum value	Range
Total coliforms (CFU/100 mL)	8.03×10^7	2.39×10^7	6.60×10^5	2.10×10^8	2.09×10^8
Fecal coliforms (CFU/100 mL)	5.63×10^5	6.95×10^4	3.20×10^3	8.56×10^6	8.55×10^6
Fecal streptococci (CFU/100 mL)	2.38×10^2	1.21×10^2	8.00×10^0	9.00×10^2	8.92×10^2
S. aureus (CFU/100 mL)	0	0	–	–	–
P. aeruginosa (CFU/100 mL)	1.99×10^4	2.92×10^3	2.00×10^2	1.57×10^5	1.57×10^5
Coliphages (PFU/100 mL)	< 1	< 1	–	–	–

Family of Two Adults and One Child

Graywater was sampled from the collection sump in 1986 and 1987. The average pH recorded was 6.87, and the average turbidity was 69.04 NTU. BOD, TSS, SO_4, and Cl averaged 119.75 mg/L, 49.16 mg/L, 30.19 mg/L, and 9.8 mg/L, respectively.

The graywater was analyzed for total and fecal coliforms and heterotrophic plate count (HPC) bacteria. The total and fecal coliforms averaged 1.92×10^8 CFU/100 mL and 1.07×10^7 CFU/100 mL, respectively. HPC bacteria averaged 1.50×10^9 CFU/100 mL (3,7).

Comparisons

There was no statistically significant difference in levels of total coliforms between the two households ($p=0.45$). However, there was a statistically significant difference in levels of fecal coliforms ($p=6.72\times10^{-5}$). Levels of fecal coliforms were higher in the household of two adults and one child. There was a statistically significant difference in levels of pH ($p=1.2\times10^{-5}$), turbidity ($p=0.0063$), chlorides ($p=1.26\times10^{-6}$), sulfates ($p=4.81\times10^{-5}$), and BOD ($p=2.71\times10^{-5}$) between the two households. Turbidity and BOD were higher in the household of two adults and one child. The household of two adults had higher pH, chlorides, and SO_4. There was no significant difference in levels of TSS between the two households.

DISCUSSION

This study shows that total and fecal coliforms, fecal streptococci, and *Pseudomonas aeruginosa* are present in graywater. The fecal coliforms indicate fecal contamination of the water (8). Just how contaminated is this graywater? The levels of microorganisms found in this water can be compared with those found in untreated and treated municipal wastewater. Total coliforms are typically found in raw wastewater in concentrations of 10^7 to 10^{10} CFU/100 mL (9) and in treated wastewater from <1 to 10^4 CFU/100 mL (1). A study from a St. Petersburg, Florida treatment plant measured 1.5×10^6 CFU/100 mL of total coliforms in secondary effluent (10). Total coliforms in the untreated graywater analyzed in this study averaged 8.03×10^7 CFU/100 mL, which falls in the range of raw wastewater. Fecal coliforms are found in untreated wastewater in concentrations of 10^5 to 10^7 CFU/100 mL, and 1.9×10^5 CFU/100 mL have been found in secondary effluent (10). Fecal coliforms in this study averaged 5.63×10^5 CFU/100 mL, again consistent with the levels found in raw wastewater or secondary effluent. Fecal streptococci range from 10^4 to 10^6 CFU/100 mL in untreated wastewater, and a Virginia study found an average of

2.18×10^3 CFU/100 mL in secondary effluent (10). Fecal streptococci in the Casa del Agua graywater averaged 2.38×10^2 CFU/100 mL, one or two orders of magnitude below the levels usually found in secondary effluent. *Pseudomonas aeruginosa* can be found in raw wastewater at concentrations ranging from 10^3 to 10^4 CFU/100 mL (9). *P. aeruginosa* in the Casa graywater averaged 1.99×10^4 CFU/100 mL, consistent with raw wastewater.

Some chemical and physical data for this water can also be compared with the characteristics of municipal wastewater. Turbidity in treated wastewater ranges from 1 to 30 NTU (1). The turbidity of the untreated Casa graywater averaged 43.00 NTU, more turbid than typical treated wastewater. This may be due to the levels of microorganisms in the graywater, as there is usually a relationship between bacterial numbers and turbidity (8). The BOD of raw sewage is about 300 mg/L (8) and drops to 10–30 mg/L in treated wastewater (1). The BOD of the Casa water was 64.85 mg/L, much less than raw sewage but still higher than treated wastewater. Like turbidity, BOD is related to levels of microorganisms in the water (8). The average concentration of TSS in untreated wastewater in the U.S. is 192 mg/L (11), and it ranges from < 1 to 30 mg/L in treated wastewater (1). The TSS in the Casa water averaged 35.09 mg/L, slightly higher than that of treated wastewater. Chlorides in untreated wastewater can range from 30 to 100 mg/L (11). The Casa graywater had an average chloride level of 20.54 mg/L, lower than that of untreated wastewater.

CONCLUSIONS

A statistically significant difference in levels of fecal coliforms was found between a household of two adults and a household of two adults and one child. The levels of fecal coliforms were higher in the household with the child. The difference in levels of total coliforms between the two houses was not significant. This may indicate that the presence of one more person in the household, specifically a child, does not significantly increase the overall number of coliforms, but it does increase the number of coliforms that are of fecal origin.

This study suggests that the overall microbial, chemical and physical quality of untreated household graywater lies somewhere between raw wastewater and secondary effluent. This water would need treatment in order to meet the Arizona standards for graywater for surface irrigation use (Arizona Administrative Code, R18-9-701-707). The standards require fecal coliform levels of 25 CFU/100 mL (geometric mean) in a series of five in one calendar month with one series per year minimum and a single sample not to exceed 75 CFU/100 mL. A chlorine residual of 2.0 mg/L is also required.

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