REUSE OF URBAN WATER: IMPACT OF PRODUCT CHOICE

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Abstract. The toxicity of individual products has been measured in relation to a marine luminescent bacteria and a biological community within a grey water treatment technology. The results demonstrate that brand labeling provides no evidence about the relative toxicity of a product including those labeled as environmentally friendly. Overall, the only products seen to be a potential risk to reuse treatment technology is bleach and car oil with secondary risks associated with washing powder and vegetable oil.

Keywords: grey water, toxicity, reuse

1. Introduction

The availability of a sustainable supply of fresh water has always been central to the development of urban centres around the world. In more recent times, increased attention has been placed on water due to increases in both population and water demand per capita. Management of such issues involves multiple options including the decentralization of wastewater treatment and the potential reuse of water from either black or grey water sources. The distinction between the two is the input of water flows from the toilet in the case of the former and excluded in the case of the latter.

On a volume basis, 75% of the total wastewater flow to domestic sewers is derived from grey water sources yet there has been a paucity of investigation into the nature of these flows. In one such study Erisksson et al. (2002) revealed 900 potential substances in a survey of products used in Danish households.

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Similarly, around 200 Xenobiotic compounds (XOCs) were detected in an audit of grey water derived from bathroom sources (Erisksson et al., 2003). The dominating sources of XOCs are expected to be derived from the chemicals used within the household in combination with personal care products. The biggest sources by mass will be the laundry powders and washing products used on a regular basis yet relatively little is understood about the impact of such products on the toxicity of grey water and its treatability. Further, there is a need to understand the role of product choice on the nature of grey water and how this may affect its ability to be treated to an acceptable standard for reuse. In addition to the regular products discharged into the sewer a number of products can be discharged on a occasional basis and these may have a dramatic impact on the treatment processes and the overall acceptability of the water for reuse. The current paper aims to investigate these issues in order to begin to understand the role of consumer choice and habits on the characteristics of grey water and its ability to be treated for reuse applications.

2. Materials and Methods

A questionnaire survey on consumer behavioral patterns was distributed to 520 people of whom 341 replies were received covering a mixture of gender, age and social groups within the UK. The aim of the survey was to determine the following:

- What frequency different substances were discharged into a grey water sink
- Which substances were perceived as being harmful to the environment

The survey asked people to indicate the frequency which they dosed each substance into a bath/sink/shower. The survey then asked each respondent to indicate which 3 of the substances listed they considered to be harmful to the environment. Products were purchased from a national supermarket chain and selected as common examples of each category of product based on there relative coverage on the supermarket shelves. The toxicity of each product was assessed in relation to either response to a specific bacteria or to a active biomass used in the treatment of grey water. Specific bacterial toxicity was measured using a Microbics M500 toxicity analyser (Azur Environmental, UK) based on the response of a marine luminescent bacteria (Vibrio fischeri NRRL B-11177) to determine the median effective concentration EC_{50}. Biomass toxicity was measured in an 11 channel closed cell aerobic respirometer (CES ltd, UK). Biomass was taken from a membrane bioreactor treatment grey water under steady state conditions. In each cell 20 mL of washed biomass, 30 mL of grey water and 10 mL of the test component were combined and the standardized oxygen uptake rate measured for 24 hours. In each run, a control cell was measured by adding de-ionised water instead of the test product and data only analysed if the control was consistent with previous runs.

3. Results and Discussion

3.1. PRODUCT TYPE

Comparison of the toxicity of products revealed the most toxic products to be the bleaches and the laundry powders whilst the shampoos were the least toxic (Figures 1a and 1b). To illustrate, the $\log_{10}$ EC_{50} values for the branded version of each product were 2.01 µL.L^{-1} for the shampoo compared to 0.83 and 0.30 µL.L^{-1} for the laundry powder and bleach respectively. All other products had a $\log_{10}$ EC_{50} value between 1.00 and 2.00 µL.L^{-1}. Analysis of the data with respect to whether the product was commercially branded, an own brand or an environmentally labeled brand revealed no consistent trend with respect to toxicity ranking. For instance in the case of the shampoo and shower gel the ranking of products from most to least toxic was Own brand, branded and environmentally branded (Figures 1a and 1b). However, in the case of laundry powder the ranking was environmentally branded, branded and own brand. It must be noted that in many cases the differences in toxicity levels were below the error levels of the test and as such no real difference could be recorded. Importantly, the data indicates that product selection based on labeling is no indication of the toxicity of the product. More specifically, purchase of products labeled as environmentally friendly do not demonstrate a lower toxicity as is perhaps perceived by the consumer.

Comparing the two techniques employed revealed that in the majority of cases a lower EC_{50} value was recorded for specific bacterial toxicity as opposed to biomass toxicity (Figures 1a and 1b) by 1 to 2 orders of magnitude. To illustrate, the $\log_{10}$ EC_{50} values for the environmentally labeled washing up liquids were 1.01 and 2.22 µL.L^{-1} with respect to the specific bacterial toxicity and 4.46 and 4.32 µL.L^{-1} with respect to community toxicity. Comparison of the two techniques revealed no consistency with respect to toxicity level, indicated by the ratio of the EC_{50} values of both techniques, or the ranking of the products apart from that the bleaches and laundry powders come out as the most toxic.

More detailed analysis within each product group was conducted to assess the impact of product choice by labeling, price and profile of the most common users. The later was identified though a focused panel discussion and separated into broad grouping based on age, gender etc. EC_{50} values with respect to specific bacterial toxicity revealed no consistent trend based on any factor. For example in the case of shampoo the $\log_{10}$ EC_{50} varied between 0.89±0.61 µL.L^{-1} and 9.93±5.85 µL.L^{-1} (Figure 2). Whilst there is a clear difference due to product choice it was not consistent through the study indicating that there is no clear selection basis for ensuring lower toxicity products are used.

Investigation into the specific chemicals in each product is difficult but some common components can be identified. In the case of the human washing products, for example shampoo and shower gel, ingredients such as sodium lauryl sulfate (SLS) and essential oils are likely to be the most toxic components. Indeed, the US EPA toxicity database reports the EC_{50} of SLS to

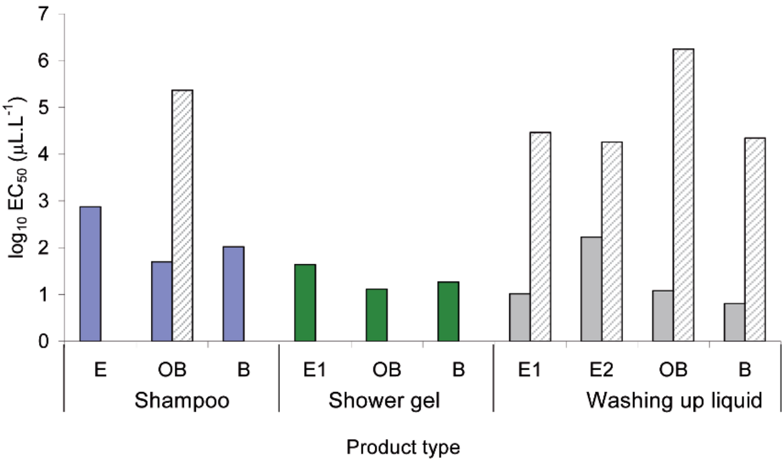

Figure 1a. Toxicity determination for generally used household products. For each product type the filled in box relate to microtox data and the hatched boxes relate to respirometry data

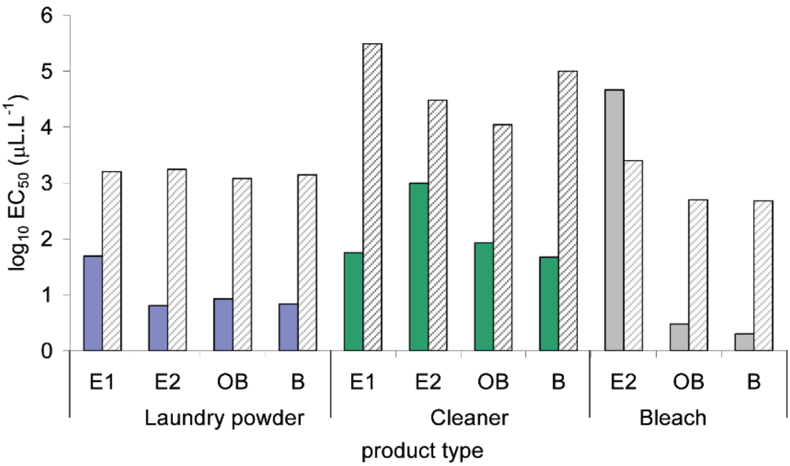

Figure 1b. Toxicity determination for generally used household products. For each product type the filled in box relate to microtox data and the hatched boxes relate to respirometry data

be between 8-41 $mg.L^{-1}$ based on *daphnia magna* toxicity (Pidou, 2006) which is within the range measured in the current study. In the other products surfactants and sodium hypochlorite are the key ingredients with respect to toxicity. Specific surfactants are not commonly reported on product labels but previous studies have reported synthetic surfactants such as linear alklybenzene (LAS) and alklyphenol ethoxylates (APEO) which are know to be toxic and very resistant to biodegradation (Pidou, 2006). EC_{50} levels for some potential compounds have been measured such as LAS with a level around 15 $mg.L^{-1}$ (Pidou, 2006). Less commonly reported is the toxicity of essential oils which can be very toxicity and are known to be used as a disinfectant in some industrial situations. As an example, the EC_{50} of clove bud oil is 0.01 $\mu L.L^{-1}$ making the oil much more toxic than most of the other components.

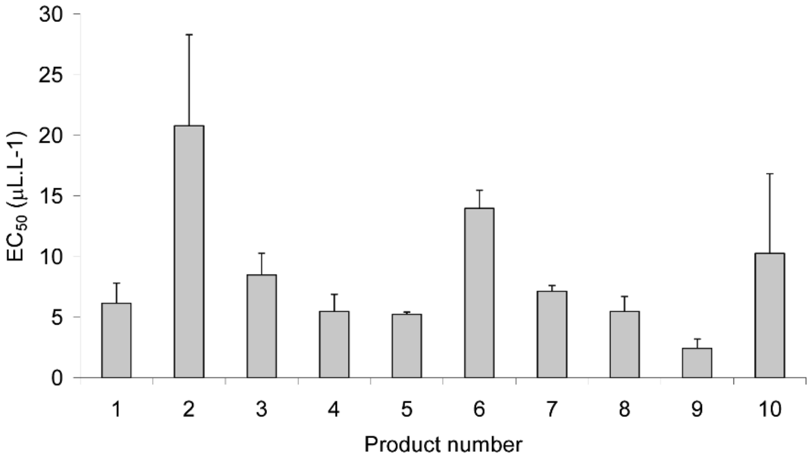

Figure 2. Toxicity of shampoo as measured by mircotox®

3.2. OCASSIONAL SUBSTANCE COMPONENTS

Results from the survey on discharge of occasional substances into grey water sources revealed that bleach (32%), body/food oil (32%), food (23%), cleaners (66%) and washing powder (27%) were identified as the most likely products to enter a grey water source as indicated by a high percentage response to the "at least once a week" category (shown in brackets) (Figure 3). Conversely, white spirits (87%), hair dye (89%), alcohol (84%), perfume (93%), body fluids (83%), Oil (94%), pet care products (96%), make up remover (84%) and caustic soda (91%) were identified are unlikely to enter a grey water source as they had a high combined percentage response to frequency ratings of "occasional", "once" and "never" categories. Analysis of the responses with respect to gender and age showed that in most case neither significantly affected the likely frequency of discharge. The exception was an increased frequency of discharge of bleach among the older respondent age group.

Bleach (18.5%), white spirits (11.1%), oil (23.8%), detergents (13.7%) and caustic soda (11.1%) were identified as potentially harmful to the environment by a significant number of the respondents. Substances that are used for direct physical human contact or ingestion, such as make up remover and vegetable oil were considered to be the least harmful to the environment. No distinct correlation between age, gender and substance was found apart from the case of caustic soda where more female respondents judge it to be detrimental to the environment than male respondents. All females and males over 26 years old perceived car oil as being the most harmful substance of those listed, whilst younger males perceived bleach to be the most harmful. Interestingly, the perception of a substance being harmful to the environment did not significantly influence the likely discharge frequency. This was most pronounced with the older respondents although in part this is due to the opportunity of discharge as much as the behavioral choice.

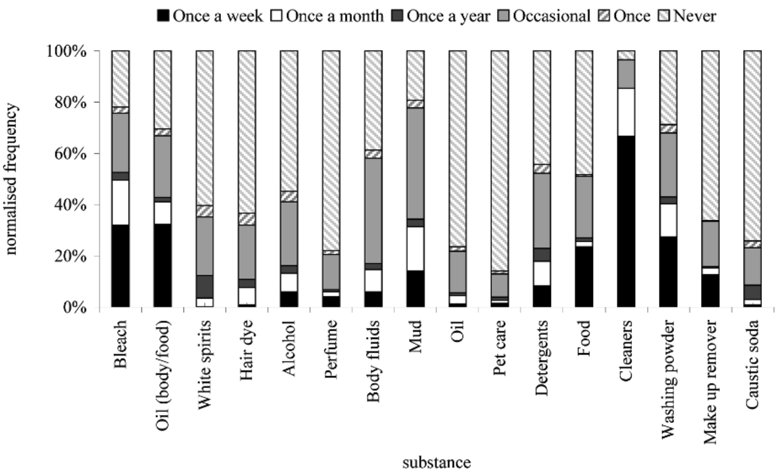

Figure 3. Normalised discharge frequency of different spiking substances

The addition of a test substance to active biomass revealed a similar pattern for most substances whereby the respiration rate initially increased then decreased once the concentration of the test substance had exceeded a critical value (C_{crit}) (Figure 4). Household cleaning products such as bleach and high strength chemicals such as car oil, caustic soda and perfume reduced the respiration rate at low relative doses (Table 1). For instance, in the case of bleach the

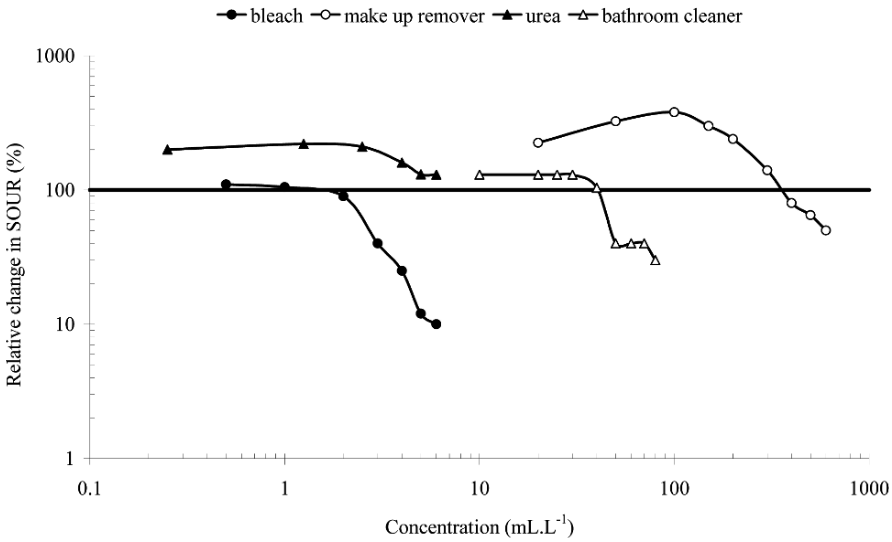

Figure 4. Relative change in SOUR when test substance is added to active biomass

TABLE 1. Critical concentrations of test substances

Substance	Ccrit ($mL.L^{-1}$)SOUR	Ccrit ($mL.L^{-1}$)pH	Spike vol. (L)	Vcrit (L)	Possible risk?
Bleach	1.4	4	4	2857	Yes
Caustic soda	4.5	<1	–	–	–
Vegetable oil	<10	Not found	4	400	Maybe
Perfume	12	Not found	0.5	41.6	No
Car oil	15	Not found	10	666	Yes
Washing powder	24	14	4	285	Maybe
Hair dye	>26	14	0.5	35.7	No
Carpet cleaner	30	Not found	4	133	No
Pet Shampoo	36	114	4	111	No
Bathroom cleaner	43	67	4	93	No
Food (soup)	60	40	1	16.6	No
White spirit	95	Not found	4	42.1	No
Alcohol (spirit)	130	240	1	7.6	No
Make up remover	320	Not found	1	3.1	No
Urea	Not found	Not found	1	–	No

SOUR fell below that of the control once the concentration had exceeded 1.4 $mL_{bleach}.L^{-1}$ (Figure 4). Beyond this concentration the respiration rate continued to decrease such that at a concentration of 6 $mL_{bleach}.L^{-1}$ the SOUR was 10% of the control value indicating that almost complete retardation of biological activity had occurred. Substances that provided relatively assailable organic material produced enhanced respiration over wide concentration ranges (urea, food, oil, alcohol). The test with food, washing powder, detergents, hair dye were restricted in concentration range due to operational problems associated with mixing or foaming indicating that spiking may cause other detrimental effects on the treatment process.

Analysis of the change of respiration rate and COD removal indicates the most probably pathway for the observed changes in activity (Jefferson et al., 2001). The observed increase in activity appeared to be due to metabolic stimulation in the case of carpet cleaner, alcohol, pet care product, make up remover, hair dye, washing powder and perfume. Whereas in the case of bleach, caustic soda and oil the observed changes appeared to be due to the uncoupling of metabolism, in which anabolism is inhibited and catabolism is not. In most cases when the dose exceeded its critical value the decrease in activity was due to metabolic inhibition. However, in the case of carpet cleaner, alcohol, pet shampoo and car oil the loss of activity appears to be due to chemical reaction between the grey water and the added substance. Analysis of the substances and there observed impacts revealed no discernible pattern or indicated any common chemical that caused a statistically apparent trend.

Another possible problem is the change in acidity of the grey water as a consequence of a spiking incident. As grey water contains little nitrogen critical pH ranges for carbonaceous oxidation are most relevant and lie between 6.5 and 8.5 (Gray, 1989). Further, depending on the probably standards that are imposed a pH criteria may exist which is likely to stipulate that the final grey water must be within the range 6–9. Critical concentrations of <1 $mL.L^{-1}$ (caustic soda), 4 $mL.L^{-1}$ (bleach), 14 $mL.L^{-1}$ (hair dye), 14 $mL.L^{-1}$ (washing powder) and 67 $mL.L^{-1}$ (bathroom cleaner) were observed due to increased pH beyond a value of 8.5. Whereas, in the case of food (40 $mL.L^{-1}$), and pet shampoo (114 $mL.L^{-1}$) the pH was reduced below the critical threshold. In the case of caustic soda, washing powder and hair dye the critical concentration due to pH was lower than that for respiration and was used in all further analysis.

To assess whether a potential chemical spiking event poses a process risk to a biological system it is necessary to estimate whether C_{crit} can be reached. The estimation comprises of two components: (1) what is likely volume of grey water the substance will be spiked into and (2) what is the maximum likely spike volume for each substance. Investigations into water saving efficiency in buildings have shown little improvement once the storage volume exceeds 150 L for single houses (Dixon et al., 1999a). In larger applications, which are more likely to involve biological processes, storages volumes are sized to avoid residence time beyond 24 hours due to concerns of water quality transformations and storage volume around 1 m^3 are often reported (Dixon et al., 1999b). Obviously the storage container may not be completely full at the time of any spiking event and so partial volumes need to be considered. Taking a grey water production rate of 100 $L.h^{-1}.d^{-1}$ and a minimum fill percentage of 50% of the storage volume then a sensible minimum grey water volume would be 500 L (equivalent to a 10 person occupancy building). Maximum spike volumes realistically can be assumed to equal the whole contents of one container of that substance (Table 1) and typically vary between 4 L for bleach to 0.5 L for perfume.

Combining the critical concentration and the maximum likely spike volume estimates a critical volume (Table 1). The critical volume represents a threshold level beyond which any storage volume would be able to buffer out any potential negative impacts. Comparison of the critical volumes indicates that bleach (V_{crit} = 2857 L) and oil (V_{crit} = 666 L) pose the only genuine process risks to biological activity. Under the current set of assumption bleach continues to be a potential risk up to populations of around 60 occupants. Vegetable oil and washing powder were indicated as possible risks if small storage volumes were used.

4. Conclusions

The experimental work described in this paper demonstrates that in terms of acute toxicity, as measured against either specific bacteria or an active community, brand selection has little relevance in informing about the impact of the product. Indeed, products labeled as environmentally friendly were shown to be no different to all the others tested within the framework of the study. A difference between specific bacteria and community is also shown suggesting that the impact of the toxicity is less likely to effect biological treatment systems than other potential areas of concern and that considerable volumes of the given products are required before any expected impact is likely to be observed. More detailed investigation into substances that can occasionally enter grey water sources reveals that whilst many substances have the ability to cause deterioration in the performance of biological systems the only products of real concern are bleaches and car oil. Secondary concerns exist for washing powders and vegetable oil.

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