Guidelines for Greywater Re-Use: Health Issues

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Abstract

This paper discusses the potential threat to health associated with the microbial contamination of greywater. Although it has been shown that greywater may contain large numbers of potentially pathogenic micro-organisms, the incidence of disease is dependent upon more than just the concentration of organisms. Other factors include the degree of exposure and the health and age of affected individuals. Proposed guidelines for the re-use of greywater focus upon faecal coliform contamination and suggest limits based upon the end use of recycled water.

The paper (a) proposes modifications to the guidelines to better represent the delicate balance between protection of public health and the levels of risk posed by greywater re-use within the context of everyday human activity, and (b) attempts to identify areas where there is either an expectation for responsibility or a personal acceptance of responsibility with regard to public or personal health.

Key words: **Exposure; greywater; guidelines; risk.**

Introduction

During recent years, the concept of greywater re-use, i.e. the re-use of wastewater from buildings excluding that fraction discharged from the WC, has assumed an elevated profile. This profile is evident in industry, academia, government and the public domain. Although debate on leakage, hose-pipe bans and metering has taken centre stage, greywater re-use has found itself a niche in the water industry as an option with much water conservation potential. The value of work such as that documented by the Building Services Research and Information Association (BSRIA)[1] forms a platform on which further informed debate may lead to realistic and workable guidelines so that the environment, industry, regulators and the public may benefit from the potential offered by greywater re-use.

The scope of this work extends only as far as the potential threat to health from non-potable greywater re-use associated with the microbial contamination of greywater. If greywater re-use is to be considered for potable use, further assessment of the risks involved would become necessary.

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Hazard Identification

It has been shown that greywater can contain at least 10^5/100 ml of potentially pathogenic micro-organisms[2,3,4]. It is also accepted that stored greywater undergoes changes in quality which include growth in numbers of micro-organisms according to the limiting factors for each particular micro-organism. Research has shown that counts of total coliform and faecal coliforms (FC) increased from 10^0–10^5/100 ml to above 10^5/100 ml within 48 h in stored greywater from various sources[5]. Of more concern is the potential infection route that greywater provides for viral infection. Viruses comprise a serious risk to health, which is amplified by the relatively low dose required to cause infection. The number of viruses found in greywater is dependent upon the health of the population generating the liquid because only infected individuals may excrete a virus, although the individual need not show symptoms of infection[6]. As the population increases, there is an increased probability of finding a virus in that greywater; in addition, viruses have been demonstrated to be persistent in the liquid[2]. Difficulties associated with the isolation and enumeration of viruses in wastewater have promoted the use of indicator organisms to indicate the degree of bacteriological (and the potential for viral) contamination. Historically, the indicator organism of choice has been faecal coliforms, particularly numbers of *E. coli* in a sample. However, the choice of indicator organisms has been, and still is, the subject of much research and discussion[7,8,9].

Dose-Response and Exposure

There is only limited dose-response information available for pathogenic bacteria and viruses[10], and Table 1 is a summary of the infective dose of some known microbial pathogens. The enteric bacteria are of particular interest because these have been shown to contaminate greywater. The general consensus is that exposure to contaminated water is predominantly a function of the re-use application[1,11,12] and occurs either at source, in transit or storage, or at use. The range of human exposure to greywater extends from ingestion (voluntary/involuntary) through skin contact, to complete isolation of greywater from human contact.

Microbial contamination of greywater comprises a potential risk to health, i.e. a risk which is likely to increase if the microbial contamination is increased. Nevertheless, the incidence of disease is dependent upon more than just the concentration of pathogenic organisms; factors of exposure, health and age of the individuals should also be considered.

Table 1. Number of viable bacteria required to cause infection in 50% of individuals exposed

Micro-organism	Number known to cause infection
Salmonella Typhosa[3]	10^6–10^8
Shigella Dysentria[3]	10^3
Pathogenic enteric bacteria[3]	10^6–10^8
Poliovirus 1[10]	72 (oral)
Echovirus 12[10]	35 (oral)
Adenovirus 4[10]	1 (nasal)

Characterization of Risk

By drawing together components of hazard, dose-response and exposure, it is possible to make comparisons between different modes of re-use. Table 2 shows estimates of the maximum and minimum bounds associated with variations in the population, human exposure, dose-response and time elapsed between generation and application. A scale of lower, intermediate and higher risk from greywater re-use is subjectively applied to each factor.

Table 2. Conceptual analysis of range of risk from greywater re-use

	Lower risk	Intermediate risk	Higher risk
Population	Small population (single family)		Large population (multi-occupancy)
Exposure	No body contact (Sub-surface irrigation)	Some contact (WC flushing, bathing)	Ingestion (Drinking)
Dose-Response	<1 Virus per sample <1 Bacteria per sample		>1 Virus per sample >10^6 Bacteria per sample
Delay before re-use	Immediate re-use	Re-used within hours	Re-used within days

The concept described in Table 2 can be taken a step further. An arbitrary scoring system, similar in format to that employed in some COSHH assessment procedures, can be applied to the range of hazard and exposure. The lower end of the significance scale is set at 1 and the higher end at 5. Table 3 shows how this scoring system has been applied to the re-use of domestic bathwater and how the estimated degree of risk varies from greywater generation through transit or storage to its ultimate application. The relative hazard of bathwater is defined as being 'intermediate to higher', which corresponds to a 'significance factor' value of 4. The human exposure to greywater whilst bathing is high because it includes partial immersion and possible ingestion, and corresponds to a higher 'significance factor' value of 5. The subsequent combination of these two 'significance factors' for different stages of the re-use process enables a subjective, yet clear, comparison between aspects of greywater generation and re-use to be made. Of particular interest is how exposure and hazard vary as numbers of potentially pathogenic micro-organisms increase over a given duration.

It is worth noting that, according to this means of classification, the human exposure to greywater at source (e.g. taking a bath) is estimated as a medium-high risk to health, due to its exposure characteristic and the possibility of faecal contamination in bathwater. Despite the arbitrary nature of this risk classification, the point remains the same; should the seemingly (and practically) harmless activity of taking a bath be regarded as a health risk comparable in magnitude with that associated with flushing the WC with greywater? The answer appears to be in identifying the real hazards associated with the re-use of fresh and stored greywater at different scales and for different applications. In addition, it is important to communicate the associated risk in a manner which promotes an understanding, and therefore acceptance, of what appears to be a radical departure from the accepted norms.

Epidemiology for Greywater Re-Use

In the absence of specific epidemiological studies on the health impact of greywater re-use, it is possible to use case studies and comparative data[10]. The countries of Japan, USA, Australia and Germany have some recent experience in greywater re-use both in research and

Table 3. Comparison of risk associated with greywater re-use at source, in transit and at point of use

		At source (e.g. bath/shower)	Score	In transit or store	Score	At point of use	Score
A	Hazard	Interm-Higher	4	Higher	5	Higher	5
B	Exposure	Higher	5	Lower	1	Intermediate	3
C (A*B)	Risk	Interm-Higher	*20*	Lower	*5*	Intermediate	*15*

TIME

private enterprise. However, most published work refers to the re-use of partially treated domestic sewage rather than greywater. The suggested applications (WC flush and irrigation) are common to both greywater and partially treated domestic sewage, and concern over impacts upon public health are shared by applications of water. The state of New South Wales in Australia and the state of California in the USA have both produced guidelines for the design of greywater re-use systems[11,12]. These have been used mainly for facilitating irrigation of domestic gardens, and have been described by some critics as being unnecessarily restrictive[13].

Water Re-Use for Irrigation

Water re-use for irrigation is undertaken on a worldwide scale, particularly in arid regions, to supplement water resources. The recycled water is subject to water-quality criteria to minimize the potential health risk without being prohibitive in terms of cost or technology. In California, the guideline value for bacterial counts in reclaimed water for irrigation is 2.2–23 FC/100 ml, the USEPA set the guideline at 200 FC/100 ml, and the WHO suggest 200 or 1000 FC/100 ml. The sources of these figures also refer to various conditions for re-use such as treatment and application restrictions[14,15].

Water Use for Recreation

The use of water for recreation can be compared to greywater re-use in terms of microbial contamination and exposure. In a situation similar to water re-use, limiting water-quality criteria are employed to minimize the potential health risk without requiring prohibitively expensive treatment. The subject of marine bathing and the potential health risk associated with the microbial quality of marine bathing waters is the subject of vigorous debate, the outcome of which might have ramifications on the review of water-quality criteria for re-use. This is particularly poignant because some proponents of greywater re-use have suggested EC bathing-water criteria for bacteria as a model for greywater re-use[16]. The EC bathing-water standard requires the water to contain less than 2000 FC/100 ml[17]; this suggestion is founded upon the comparison of exposure potential between recreational bathing and some types of greywater re-use, and both may involve a degree of body exposure and accidental ingestion.

Micro-Organisms in the Built Environment

In the built environment, domestic or otherwise, there are many established micro-organisms to human-exposure routes. However, if greywater re-use is introduced into peoples' homes or workplaces, another possible route of infection is being provided[18,19].

Outbreaks of Legionnaires' disease have been connected with the presence of *Legionella pneumophila* – a naturally occurring bacterium in domestic hot-water supplies, shower heads, cooling waters and other water services in buildings[20]. The route of infection is by inhalation of aerosols into the lungs of an individual, although the infective dose of *Legionella pneumophila* is not known. The bacterium is naturally resistant to water-treatment processes; therefore, if bacterial growth is not effectively treated on-site, it can become a serious problem[21]. It is possible that greywater-recycling equipment might provide a haven for the proliferation of the legionella bacteria. Factors promoting growth include surface fouling, biofilm formation, slow-moving or stagnant waters, and elevated temperatures (20–45°C), all of which are potentially associated with greywater collection, storage and re-use. The proliferation of legionella bacteria must be controlled to prevent infection by improving water-distribution systems together with a regular inspection and maintenance programme.

Proposed Guidelines

Relevant guidelines are included in the BSRIA report[1], and are derived from an extensive literature review of national and international practice of greywater and rainwater re-use. The water-quality criteria focus upon faecal coliform contamination and suggest limits based upon the end use of recycled water, and this is consistent with the modern paradigm of water-quality legislation. However, the guidelines do not clearly state the point in the water re-use cycle at which the coliform limits should be applied. Also, there is an exception in the proposed water-quality limits for hand-basin toilets (a device in which the hand basin forms part of the WC unit and discharges washwater to the WC flush). These limits are based upon a re-use system design rather than the end-use of the water. In fact, there is no proposed limit on the number of faecal coliforms for hand-basin toilets in contrast to the 0/100 ml faecal coliforms stipulated for other 'non-hand-basin' greywater re-use devices. It is interesting to note that the USA branch of a major bathroom goods manufacturing company no longer produces a hand-basin toilet model because it is not included in building regulations[22]. In addition, the report and subsequent proposed guidelines make no comment on essential differences between single-user and multi-user greywater re-use, even though the size of the contributing population has some bearing upon the associated health risk of greywater re-use.

Distinction Between Single Family and Multi-Occupancy Greywater Re-Use

Human interaction with a greywater system would normally be as a 'user' or as an 'owner'. In a commercial or municipal building, the owner and the user comprise two distinct groups; moreover, the owner may be the employer of the user and, as such, has a duty of care to ensure the health and safety of employees. In terms of greywater re-use, this could mean that the responsibility for the initial purchase, maintenance, health and safety lies entirely with the owner. However, in the domestic situation where the number of occupants is lower and less transient, it is the occupants who assume responsibility for the purchase, maintenance and health and safety.

Table 4. Framework for water-quality guidelines of greywater re-use in UK

Category	Sector	Occupancy	Application	Relative magnitude risk in comparison to using potable quality water (Table 2)	Example limits for indicators of faecal contamination e.g. *E.Coli* (count/100 ml)
1	Industrial commercial municipal	Multitransient	All	Higher	0[1]
2	Domestic	Multitransient	All	Higher	0[1]
3	Domestic	Single family resident	WC flush	Intermediate	Limit based on design criteria not water quality*
4	Domestic	Single family resident	Outdoor**	Intermediate–Higher	200–1000[15]

Notes: *Subject to certain design criteria set by the regulating authority, defined in text.
**Re-used in the garden or for exterior washing.

Proposed Framework for Guidelines to Re-use of Greywater

A framework for guidelines to the re-use of water is proposed (Table 4) based upon the findings of this basic risk assessment and the BSRIA recommendations[1]. The use of faecal coliforms as an indicator of the microbial quality of greywater remains a viable option considering that the origin of contamination is primarily faecal material. The principal amendment is in the distinction between multi-user and single family water re-use. Secondly, the evidence which is presented in this paper is not sufficient to justify the setting of an absolute number of faecal coliforms which must be achieved in recycled water, particularly in the absence of sufficient dose-response data for the relevant pathogens and epidemiological data for greywater re-use. Therefore, reference has been made to existing relevant guidelines such as those proposed by BSRIA for greywater and those proposed by the WHO for the re-use of treated effluent.

It is proposed that for categories 1, 2 and 4, guidelines such as the WHO guidelines for water re-use with partially treated domestic sewage should be adopted in a specific manner. In addition, research should be carried out with a view to extending any microbial limits to include other micro-organisms (including enterococci) in line with regulations for recreational waters and in the light of renewed debate on the applicability of indicator organisms. Regulation of the domestic greywater re-use in a single family home for the purpose of WC flushing (category 3) should move away from placing a limit on the number of faecal coliforms. Instead, there should be strict criteria for design aspects such as system sizing, treatment, maintenance requirement and operation so that:

(a) The residence time of greywater in the system is kept to a minimum in order to minimize microbial proliferation;
(b) Human exposure to greywater is kept to a minimum;
(c) Odour is kept to a minimum;
(d) Biofilm is prevented; and
(e) Components are clearly labelled.

Consideration should be given to the idea that installation is carried out by a professional person who is registered with an appropriate regulating body. The concept of an accredited test-house, introduced in BSRIA's report[1], should be developed. It could also be necessary to include a maintenance contract as part of the purchase deal for greywater systems. Using greywater for certain outdoor applications should be subject to the same restrictions as categories 1 and 2, because it is possible that any aerosols would be transferred to adjacent properties. Outdoor applications such as trickle or sub-surface irrigation could be considered alongside category 3 use.

Conclusions

1. A framework for guidelines for the re-use of greywater has been proposed, which forms a summary of a desk-top risk-assessment study sourced from current and long-standing published material on risk, greywater re-use and other modes of water re-use.
2. The framework takes into account the paramount importance of protecting public health whilst recognizing the realistic levels of risk posed by various modes of greywater re-use within the context of everyday human activity.
3. Areas where there is either an expectation for responsibility or a personal acceptance of responsibility with regard to public or personal health, have been identified.

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