Safe on-Site Reuse of Greywater for Irrigation - A Critical Review of Current Guidelines

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Reuse of greywater for landscape irrigation can significantly reduce domestic water consumption. Alongside its benefits, there are potential drawbacks to greywater reuse, raising legitimate concerns about the impact on human and environmental health. In this review, a risk assessment framework is used to assess the adequacy of different regulations to ensure safe and long-lasting, onsite greywater reuse for irrigation. Existing regulations from around the world are assessed along with a standardized evaluation of measures taken to protect public and environmental health. In most cases, human health considerations currently dominate regulatory strategies, while environmental risks are either ignored or underrepresented. A distinction between single and multiple households was found to be a fundamental component of the regulations which often lead to approved utilization of untreated greywater among single households. We concluded that the use of untreated greywater is not recommended, especially in multihousehold systems as it may compromise public health, with single household systems posing more likely risks to the environment. Existing rules to control greywater use should be further revised toward the establishment of a more advanced regulatory system which can avert the salient potential risks associated with greywater reuse, while exploiting the enormous potential of this alternative water resource.

Introduction

The steady growth in world population and improvements in the standard of living place increasing pressures on the world's water resources, contributing to their depletion. One approach to ameliorating water quantity problems which has gained popularity in recent years is the separation of "greywater" from general sewage, for the purpose of onsite treatment and reuse. Greywater is defined as "all domestic sewage, with the exception of wastewater generated by toilets and bidets". Greywater is mainly comprised of effluents from showers, washbasins, and laundry. Kitchen effluents are often referred to as part of the blackwater (water that contains toilet discharges) (*1, 2*).

Greywater comprises about 50−75% of domestic water consumption (*2−4*). The reuse of greywater for toilet flushing and garden irrigation has an estimated potential to reduce domestic water consumption by up to 50% (*3, 5, 6*). Thus greywater reuse can alleviate stress on depleted water resources while reducing water costs for residents. It can decrease the pressure on central sewage conveyance and treatment systems (that in many cases are already overloaded) and enable stable water supply for year round gardening, even in times of droughts. The reuse of greywater, however, also can compromise human and environmental health. Pathogens in greywater may cause diseases through direct contact as well as through the consumption of contaminated plants (*7, 8*) and/or through peripheral vectors like mosquitoes (*9*). Additionally, greywater can contain elevated levels of surfactants, oils, boron, and salts, which may alter soil characteristics, damage vegetation, and pollute groundwater (*10−12*).

Both the associated challenges and opportunities should be taken into account when considering greywater reuse policy. For greywater to be more accessible, reuse schemes must be simple and economical, encouraging wider use, thereby maximizing the quantity of water saved. At the same time, greywater reuse must be environmentally sound and avoid any attendant public health insults.

Several jurisdictions have established standards for greywater reuse, but the variation between policies is great. Often, policies do not differentiate between black and gray waters or even formulate specific regulation for greywater reuse. Several states such as in the U.S. and in Australia, however, recognize the benefit of onsite reuse of greywater and have created highly detailed normative frameworks (*1, 2, 13−15*).

In this review, risk assessment tools are used to form a baseline for a standardized evaluation of existing regulations and measures that should be taken to protect public and environmental health. In the first part, the four stages of Quantitative Microbial Risk Assessment (QMRA) are used as the basis for examining public health related guidelines. In the second section, a similar method is used to investigate the environmental hazards and the few existing related guidelines. A short review of different administrative approaches is given in the last part of the review.

Public Health. Greywater is often considered by the public as safer than blackwater (*16*). However, it is well established

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TABLE 1. Possible Exposure Scenarios to Greywater

exposure scenario	quantity	frequency (events/year)
accidental ingestion of greywater (*14*)	100 mL	1
routine indirect ingestion from touching plants and lawns (*14*)	1 mL	90
ingestion of greywater sprays from the irrigation system (*14*)	0.1 mL	90
ingestion of soil contaminated with greywater (*24*)	10−100 mg	according to the number of working days in the garden
eating a home-grown plant that was exposed to greywater (*7, 14*)	0.36−10.8 mL/100g. 5 mL per serve of lettuce; 1 mL for other produce	7 for lettuce; 50 for other produce

that it can still pose considerable health risks if not used appropriately (*4, 9, 17, 18*). Pathogenic organisms in greywater may derive from three main sources: fecal contamination, food handling, and opportunistic pathogens, such as those found on the skin or respiratory organs (e.g., nose and mouth). Although greywater usually contain lower levels of fecal contamination than black water, the vast majority of the literature recognizes the presence of sundry pathogens from the digestive system (*18, 19*). A few studies have investigated the risk from food handling pathogens, such as salmonella spp (*20*), while a handful of studies have considered the risks associated with such pathogens in wastewater. Their findings can be extrapolated for greywater risk assessments. Opportunistic pathogens usually associated with skin and ears insults, such as *Pseudomonas auroginosa* and *Staphylococcus aurous*, are occasionally found in greywater (*21−23*); however, data regarding the actual health risk they pose are lacking.

In order to mitigate the potential risks associated with pathogens from these three sources, rules that create barriers to greywater reuse have been enacted. These barriers are set to minimize possible contact between humans and pathogens. In order to assess the adequacy of greywater regulations, a quantitative microbial risk assessment (QMRA) (*7, 24*) was adopted and applied. QMRA is an indirect, stepwise, approach to risk assessment based on mathematical models and experimental data. QMRA is generally comprised of four steps:

Hazard identification - Defining the hazards or finding index hazard agents that present the most prominent risks and assessing their prevalence in the relevant environment.

Exposure assessment - Assessing the routes, frequency, and duration of exposure to the hazard and the exposed populations.

Dose−response characterization - Defining the quantitative connection between the rate of exposure to the probability of becoming infected and expressing it mathematically.

Risk characterization - Integrating data from the previous steps, estimating the magnitude of risk in comparison to existing health targets, or to risks deemed "acceptable".

Mara et al. (*8*) found that using realistic values in QMRA (using 10,000 trial Monte Carlo simulations) resulted in similar risk values as those obtained by parallel epidemiological field studies.

Hazard Identification. Since it is practically impossible to identify and account for all pathogens, indicator organisms are often used in risk assessments. For instance, traditionally, fecal contamination is a central parameter in wastewater quality monitoring, and fecal coliforms is the most common indicator of the possible presence of other fecal pathogens. Moreover, they are considered as the most efficient indicators for measuring removal of bacterial pathogens (*25*). Although many reports demonstrate an elevated concentration of fecal coliforms in greywater (*4, 26*), its relevancy as an indicator for the microbial quality in greywater is disputed (*17, 18*). For example, it is well-known that fecal coliforms are not unique to human feces. Moreover, it was demonstrated that fecal coliforms are able to multiply outside of the body in an aqueous environment if they have suitable conditions and available organic matter for their growth, suggesting that their count might lead to an overestimation of fecal pollution and its associated risks (*27*). It should be noted though that fecal contamination does exist in greywater and may pose unacceptable health risks (*18*).

Viruses constitute a key component of such fecal pathogens because of the high rate of excretion from infected persons, the low dosages needed for potential infection, and their high survival rate in the environment (*15, 18, 28*). Rotaviruses are a common cause of gastroenteritis in humans (*28*), for which a dose−response model has been established. In a risk assessment conducted by Ottoson and Stenstrom (*18*) they were found to pose the most significant risk to human health from greywater. For these reasons, rotaviruses were chosen as the reference pathogens for risk assessment in this study.

Methods for quantifying rotavirus concentrations in greywater are not as straightforward and simple as those used for quantifying fecal coliforms or *E. coli*, which is a major group in the fecal coliform bacteria and is often measured as a representative indication for fecal contamination (*25*). Different studies have tried to correlate the rotavirus load with fecal indicators such as *E. coli*. The WHO guidelines (*15*) suggest that there are between 0.1 to 1 rotavirus for every 10^5 *E. coli* in 100 mL of domestic wastewater. The Australian national guidelines for water recycling (*14*) suggest an average concentration of 8000 rotavirus units for every liter of domestic wastewater, which correlates to an average density of 10^7 *E. coli* per 100 mL, or in other words, 8 rotavirus units per 10^5 *E. coli*. Ottoson and Stenstrom (*18*) discussed the ability of fecal coliforms to regenerate in greywater, causing an overestimation of fecal contamination. They proposed the use of coprostanol as a chemical indicator and tested their hypothesis in Vibyasan, Sweden. Using this indicator and epidemiological data, it was suggested that the density of rotavirus in greywater was 0.17 rotavirus units/mL (*18, 29*). Interestingly, when we apply the two estimations mentioned above (*14, 15*) for rotavirus density based on the *E. coli* counts found in Vibyasan's greywater system it results in comparable estimations as follows: 0.01−0.1 rotavirus units/mL according to WHO (*15*) and 0.8 rotavirus units/mL according to the Australian guidelines (*14*).

Exposure Assessment. Exposure rates are a key factor in determining the probability of infection. An exposure assessment should take into consideration possible exposure pathways such as all forms of ingestion, frequency, and the magnitude of exposure (e.g., the quantity ingested per exposure event). The Australian guidelines (*14*) offer examples of estimated exposures based on the volume used in gardens irrigated with wastewater (Table 1). Other exposure routes, such as those associated with the ingestion of contaminated soil, crops, or groundwater can be adapted from risk assessments employed in agricultural wastewater irrigation studies. For example, it was estimated that a quantity of 10−100 mg per person per day of soil saturated with wastewater could be ingested by people working or playing

in wastewater irrigated soils (*15*). Shuval et al. (*7*) estimated the volume of irrigation water clinging onto 100 g of cucumber and 100 g of lettuce as 0.36 and 10.8 mL, respectively. If eaten unwashed, microorganisms in the greywater that were deposited on the crops during irrigation can be ingested. The Australian guidelines (*14*) adopted data from Shuval et al. (*7*) to estimate the potential exposure to greywater following consumption of home-grown and commercial production of vegetables. An attempt to standardize and summarize these risks of exposure assessments is presented in Table 1.

Dose−Response. The probability of infection due to exposure is driven by available dose−response models. The Haas's beta-poisson dose−response model for rotavirus is used as an example of risk assessment and presented in eqs 1 and 2 (*24*)

$$Pi(d) = 1 - [1 + (d/N_{50})(2^{1/\alpha} - 1)]^{-\alpha}$$
$$\text{(For the rotavirus model } \alpha = 0.253, N_{50} = 6.17) \quad (1)$$

$$Pi_{(A)}(d) = 1 - [1 - Pi(d)]^n \quad (2)$$

where d is the dose of the pathogen, and $Pi(d)$ is the probability of individual infection or the proportion of infected people in a community as a result of each of its members exposure to a single dose "d" of a pathogen. N_{50} is the dose at which half of the population will be infected, and α is the infectivity constant of the pathogen. $Pi_{(A)}(d)$ is the annual risk of infection, and n is the number of exposure events per year.

Risk Characterization. Utilization of wastewater or greywater involves risk. Accordingly, there is a need to set a maximum acceptable risk level. Such thresholds involve ethical decisions and are a function of societal benefit-cost equations, balancing the benefits of saving water versus the costs of infectious disease. The DALY (Disability Adjusted Life Year) concept calculates both the number of years of life lost due to death (YLL) and the years lived with disability (YLD), and it is used to measure the healthiness of a society (*30*). DALY is commonly used by the WHO and other countries (e.g., Australia) as an important tool to assess maximum tolerable risks by which health targets and public health management are decided. The WHO has set 10^{-6} DALYs per person-year as the maximum tolerable risk for water borne disease (*31*). In other words, a risk is deemed tolerable if one year of healthy life is lost due to water borne disease in a population of 1 million people. The tolerable infection risk for rotavirus was calculated according to the 10^{-6} target and severity of the diseases it causes and was set as 1.4×10^{-3} infections per person per year (*15*). This, in turn, means that out of the entire population it is tolerable for about one person out of a 1000 to become infected with a rotavirus, once a year. The DALY index details are beyond the scope of this paper. For further details the reader is directed to refer to the WHO and others publications on the subject (*14, 15, 30, 31*).

In order to find the safe dose (d), it is possible to use an inverse solution to the dose−response model (eq 1) by introducing the tolerable infection risk (e.g., 1.4×10^{-3}) as the probability of infection ($Pi(d)$) as outlined in eq 3

$$1.4*10^{-3} = 1 - [1 + (d/6.17)(2^{1/0.253} - 1)]^{-0.253};$$
$$\text{the safe dose } d \text{ is therefore } 2.4*10^{-3} \text{ rotavirus units.} \quad (3)$$

Dividing the safe dose d by the estimated rotavirus densities in greywater as outlined in the Hazard Identification section would yield the maximum allowable volume of greywater that can "safely" be ingested in a single occurrence (Table 2).

The same rationale can be used to address multiple exposures using eq 2. For example, here we use data provided

TABLE 2. Maximum Greywater Dose (mL) That Can Be "Safely" Ingested by a Person, Assuming That the Greywater Contains between 0.01 and 0.8 Rotavirus units/mL Which Is Correlated to a Count of 10^6 *E. coli* 100/mL, As Estimated by Three Different Sources

method	rotavirus/mL	max dose (mL)
WHO (*15*)	0.01−0.1	0.24−0.024
Ottoson and Stenstrom (*18, 29*)	0.17	0.014
Australian guidelines (*14*)	0.8	0.003

by the routine ingestion scenario of 90 exposures for 1 mL per year (Table 1). This exposure was chosen as an example as it represents a high routine exposure in a scenario that is hard to avoid (routine indirect ingestion from touching plants and lawns). The probability of infection $Pi(d)$ followed by the safe dose (d) can be calculated as follows

$$1.4*10^{-3} = 1 - [1 - Pi(d)]^{90}; \text{ the } Pi(d) \text{ is therefore } 1.6*10^{-5}$$

The $Pi(d)$ is then plugged into eq 1 to determine the safe dose (d)

$$1.6*10^{-5} = 1 - [1 + (d/6.17)(2^{1/0.253} - 1)]^{-0.253};$$
$$\text{the safe dose } d \text{ is therefore } 1.4*10^{-4} \text{ rotavirus units/mL.}$$

Transforming the above figure to *E. coli* concentration, based on ratios suggested by WHO (*15*) and the Australian guidelines (*14*), generate a safe *E. coli* concentration ranging between 10^2-10^4 (in the case of 90 events of 1 mL ingestion annually). These results suggest that the maximum tolerable concentration of *E. coli* may lie between 10^2 to 10^4/100 mL. This substantial range may explain the differences between different regulatory guidelines. For example: the WHO wastewater irrigation guidelines limit *E. coli* concentration to 10^3 *E. coli*/100 mL (*15*), while the Israeli guidelines recommend levels 2 orders of magnitude lower at 10^1 *E. coli*/100 mL (*32*). Interestingly, the Australian guidelines suggest using log reductions rather than specifying a minimum *E. coli* concentration (*14*). It should be noted that in most risk assessments, computer simulations, such as the Monte Carlo method, with multiple trials is used to calculate risk levels (*8, 15, 18*) rather than one exposure scenario as demonstrated above.

Such low infective doses demonstrate that the use of untreated greywater may be unsafe. However, as noticed by Dixon (*17*) and the Australian guidelines (*14*), the smaller the reuse cycle, the lower the pathogen risk. In other words, reusing greywater from a single house system is much safer than reusing greywater on a neighborhood-scale system. Indeed, many states have separate regulations for single households and multihousehold systems (e.g., Arizona (*33*), Utah (*2*), Nevada (*2*), Victoria (*34, 35*), south Australia (*36*), Northern Territory (*37*), New South Wales (*38*)). This distinction can often be attributed to historical reasons rather than a conscious strategy for lowering risk.

Most regulatory programs allow restricted use of untreated greywater within the context of a single household property. Excluding kitchen effluents, enteric pathogens occur in greywater mainly if one of the people contributing to the system is a carrier. If there is one infected person in a household, others living at the same property may become infected by the pathogen in multiple pathways other than via greywater.

Following this logic, any additional household connected to a system increases the risk of morbidity. Yet, even at the single household scale, issues such as pathogen survival or regrowth in greywater conveyance systems (*18*) may pose unnecessary risk to the direct user of greywater. There is
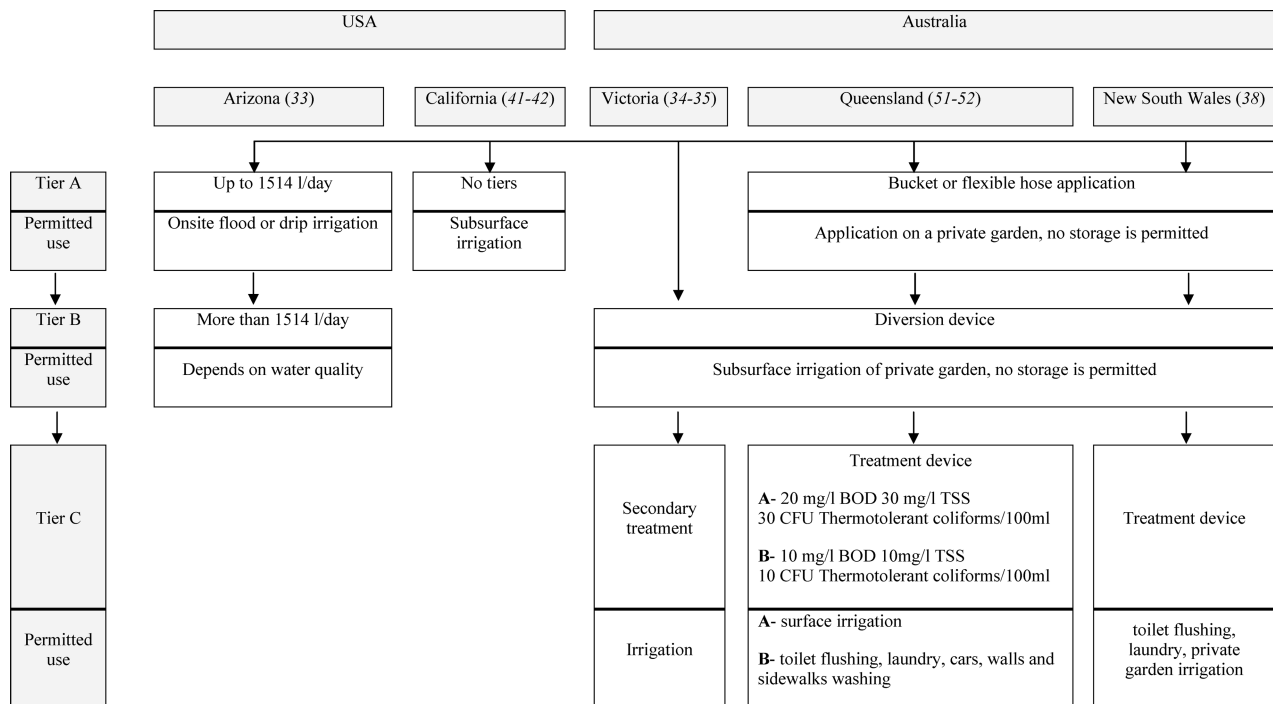
	USA			Australia	
	Arizona (33)	California (41-42)	Victoria (34-35)	Queensland (51-52)	New South Wales (38)

Arizona (33):
- Tier A / Permitted use
- Tier B / Permitted use
- Tier C / Permitted use

California (41-42):

Up to 1514 l/day	No tiers
Onsite flood or drip irrigation	Subsurface irrigation

More than 1514 l/day
Depends on water quality

Australia (Victoria, Queensland, New South Wales):

Bucket or flexible hose application
Application on a private garden, no storage is permitted

Diversion device
Subsurface irrigation of private garden, no storage is permitted

| Secondary treatment | Treatment device
A- 20 mg/l BOD 30 mg/l TSS 30 CFU Thermotolerant coliforms/100ml
B- 10 mg/l BOD 10mg/l TSS 10 CFU Thermotolerant coliforms/100ml | Treatment device |
|---|---|---|
| Irrigation | A- surface irrigation
B- toilet flushing, laundry, cars, walls and sidewalks washing | toilet flushing, laundry, private garden irrigation |

FIGURE 1. Permitted uses of greywater by different states.

TABLE 3. Exposure Scenarios and Related Common Barriers

exposure type	exposure scenario	summary of suggested barriers by different authorities
direct	accidental ingestion of greywater	wearing protection when maintaining the system
marking the pipes as nondrinkable water
	ingestion of greywater from the irrigation system	human contact is avoided
restricted spray irrigation
water should not pond
marking the pipes as nondrinkable water
	ingestion of soil contaminated with greywater	greywater applied as subsurface irrigation
overflow to sewage
indirect	inhalation of aerosols from spray irrigation system	restricted spray irrigation
	eating fresh vegetables that were irrigated with greywater	restricted food crops irrigation
	groundwater pollution	setback distance from groundwater level
	surface water pollution	water should not flow outside property boundaries
location outside drainage or flood zones
water should not get into open water bodies
overflow drains to sewage
	pathogen transmit through vectors as mosquitoes	water should not pond
overflow drains to sewage

therefore a need to promote suitable treatment, such as the introduction of basic disinfection. It should be noted that several greywater treatment systems were found to reduce *E. coli* concentration to low and even undetectable levels after the introduction of a disinfection unit (23, 39, 40). As discussed above, it should be noticed that *E. coli* is not necessarily a sufficient indicator of bacteria and may even be less appropriate for viruses, protozoa, and helminth (25). Another complementary approach can be the establishment of barriers to minimize human contact with potentially hazardous bacteria (17).

Currently, most of the regulations rely on approaches that utilize such "barriers". These can take the form of restrictions on the products and processes allowed to go into a recycling scheme, the level of treatment required or the reduction of exposure rates (14). Normative barriers can reduce the "maximum risk" measured in a risk assessment to a de minimus "residual risk" following their adoption (14). The first barrier imposed is usually placed on the source of water allowed into the reuse scheme. For example; in California (CA) the reuse of water from the kitchen is completely

proscribed (41, 42), while in New South Wales (NSW) water from kitchen streams can only be allowed if an appropriate treatment device is in use (38). Similar to this approach is the restriction on the use of water from the washing of soiled diapers in Arizona (AZ) and CA (33, 42) and the use of untreated water from that source in NSW (38). NSW has also recommended not using greywater when a person in the house has gastroenteritis (38). Other barriers focus on required treatment levels, the permitted uses of the water, and other technical barriers. Figure 1 and Table 3 summarize different solutions that have been adopted in state regulations.

Some programs have established a tiered approach, in which there are different requirements for different types of reuse schemes. For example, AZ and CA's tiered approach classifies utilization according to the size of the system where uses and system requirements are based on greywater volume (33, 42). Victoria and NSW's tiered approach is driven by treatment levels (34, 35, 38). As a rule of thumb, barriers (other than the treatment itself) are lowered, and additional

TABLE 4. Environmental Hazards Associated with Reuse of Greywater for Irrigation

parameter	examples for possible impact
pH	corrosion of equipment, damage to biota, changes in biochemical processes (4, 44)
electrical conductivity	reduction of plant productivity, possible changes in soil properties (44)
Cl⁻	accumulation in soil may adversely affect plants (10, 44)
sodium adsorption ratio	exacerbation of soil erosion, changing of soil hydraulic conductivity and reduction of plants growth (44, 45)
boron	accumulation in soil may be toxic to plants (10, 40)
phosphorus	eutrofication if excess concentrations reach surface water, inducing bio clogging of equipment (44)
surfactants	accumulation may change soil hydraulic conductivity, plant toxicity (12, 46)
oil and grease	accumulation may change soil hydraulic conductivity (11)
xenobiotics	toxicity to biota (4, 47)

TABLE 5. Description of Permit Requirements for Different States

	U.S.A.		Australia		
	AZ (33)	CA (41, 42)	VIC (34, 35)	QLD (51, 52)	NSW (38)
tier A	up to 1514 L/day	clothes washer and/or single fixture	bucket or flexible hose application	bucket or flexible hose application	bucket or flexible hose application
consumer type	single family	one or two family dwelling	not specified	not specified	not specified
permit for device	not required	not required	not required	not required	not required
permit for installation	not required	not required	not required	not required	not required
tier B	more than 1514 L/day	up to 950 L/day	diversion devise	diversion devise	diversion devise
consumer type	more than a single family	one or two family dwelling	single household	not specified	single household
permit for device	required	required	required	required	required
permit for installation	required	required	not required	required	not required
volume limitation	not specified	up to 950 L/day	not specified	up to 3000 L/day	not specified
tier C	—	more than 950 L/day	treatment device	treatment device	treatment device
consumer type	—	—	single household	all consumers up to 50,000 L/day	not specified
permit for device	—	required	required	required	required
permit for installation	—	required	required	required	required
volume limitation	—	—	up to 5000 L/day	up to 50,000 L/day	720−900 L/day

uses of the water are allowed as treatment level increases. A summary of the permitted uses at each tier is presented in Figure 1.

As demonstrated in Figure 1, most regulatory programs use multiple barriers to reduce exposure rates in order to eliminate health risks. The links between different exposure scenarios and recommended technical barriers suggested for their prevention are summarized in Table 3.

To date, no epidemiological survey supports claims that greywater usage at a single household scale is associated with higher morbidity. While the precautionary principle mandates a conservative approach to standard setting, the particularly widespread usage of greywater in Australia (55% of households) (43) may suggest that greywater utilization does not constitute an acute public health insult. Yet, attention should be given to issues such as the under reporting of gastrointestinal illness and other confounding factors that serve to mask associations between greywater use and disease. The dearth of empirical case studies and epidemiological surveys on the matter is regrettable as they would contribute to a higher quality of risk assessment. Despite the lower level of health risks typically associated with single household (as compared to multiple sources) reuse, we believe that suitable treatment and disinfection are recommended prior to all greywater reuse, irrespective of scope. Regulations should also consider and weigh the added benefits provided by additional water, as a *resource*, against any *risk* associated with its utilization.

Most regulations provide better measures for protection of public health, yet other potential environmental risks, such as soil degradation and the pollution of ground and surface water, are often overlooked.

Environmental Risks

Adverse environmental effects may occur as a result of greywater reuse for irrigation. The impact may remain local, limited to the user's property, or spread beyond to the external environment (e.g contamination of ground or surface water). At present, there is a paucity of empirical information regarding the extent and magnitude of these impacts. The current section attempts to summarize the key environmental issues/risks associated with the reuse of greywater as well as analyze simple means for remedying these concerns, based on the same principles and framework of risk assessment delineated above.

Hazard Identification. In most cases, the most significant risks are found in the immediate property. Such environmental risks are often cumulative in nature with damage only identifiable after several years of usage.

The primary environmental hazards from use of greywater for irrigation are summarized in Table 4.

Occasionally, greywater contains excessive salinity, which can reduce plant productivity and damage soil structure through a variety of different mechanisms (44). Sodium adsorption ratio (SAR) is an index describing the ratio of sodium to calcium and magnesium ions as follows: (SAR =

(Na)/[(Ca+Mg)/$_2$]$^{0.5}$). High SAR resulting from the use of sodium salts (e.g., in laundry detergents) can reduce the hydraulic conductivity of soils and cause soils to become dispersive, a phenomenon that particularly affects soils with a high clay content (45). Other elements that are used in domestic cleaning materials, such as boron and chlorides, may also compromise plant health (10, 40).

Eriksson et al. (4, 47) found 39 potentially hazardous XOCs (xenobiotic organic compounds) present in greywater. Of these, five organic compounds (dibutyl phthalate, LAS, malathion, triclosan, and hexyl cinnamic aldehyde) were found to pose a risk if directly discharged into surface water or soil beds. Moreover, parabens, a group of biocides used as preservatives in many household pharmaceuticals, found in variable concentrations in greywater, can cause estrogenic effects in aquatic organisms (48).

The highest concentration of organic chemicals in domestic greywater are surfactants (46). Recent studies have demonstrated that anionic surfactants may reduce the capillary rise or the permeability of soils (12). Even though the most common surfactants, such as LAS, are highly biodegradable, elevated concentrations of up to 40 to 60 mg/kg were found in greywater-irrigated soils (10, 12). A possible explanation for this is that strong adsorption by soil particles inhibits degradation of surfactants (12). Oils and grease are other substances commonly found in greywater that may reduce the ability of soils to convey water (11).

Exposure Assessment. Pollutant loads in greywater vary significantly from household to household and temporally. Typically, contamination depends on the quantity of water generated, the amount and kind of household chemicals used, and the residents' hygienic and other personal habits (22, 38). Naturally, the immediate soil and biota irrigated with the greywater are subject to the highest exposures to contaminants. The general environment (e.g., soil and natural water bodies) may also be affected if the greywater logs or infiltrates outside of the property.

Dose-Response. Due to the high variability of pollutants in greywater it is hard to define a safe dose for each contaminant (4). Similar to pathogen risk assessment, it is more practical to adopt a "scoping" approach, screening for risk levels in order to identify the most problematic pollutants, and only then assess their "Predicted No Effect Concentrations" (PNEC). For example, PNECs for 32 XOCs were calculated by Eriksson (47). Weil-Shafran et al. (12) found that anionic surfactant concentrations (such as MBAS) as low as 10 mg/kg$_{(soil)}$ had already reduced the capillary rise in sand. In capillary rise experiments, increasing oil and grease content from 0−250 mg/kg reduced water imbibition (in an approximate linear fashion) by up to 60% (11). In a flowerpot study, it was demonstrated that irrigation with raw greywater containing 10 mg/L of anionic surfactants and 22 mg/L of oil and grease, for a month, resulted in reduced hydraulic conductivity (measured as water droplet penetration time) of sand and loam soils. Yet the impact was not observed in loess soil (49). These data should continuously be updated as more information becomes available.

Risk Characterization. Substances that may change soil properties, and consequently reduce the efficiency of barriers against greywater penetration into water bodies, should receive special attention when assessing greywater reuse risks. These substances should be further researched to characterize a reasonably safe dose for irrigation purposes. Other priority pollutants are those that may adversely affect the greater environment, if directly discharged into water bodies or sensitive areas (e.g., natural reserves), when their predicted environmental concentration (PEC) are higher than their Predicted No Effect Concentration (PNEC).

Despite compelling evidence regarding possible health or environmental risks, in fact, very little attention has been given to existing greywater regulations' approach to environmental hazards. Certain standards address both environmental and health challenges by setting descriptive objectives, such as "avoidance of water logging" or "ensuring minimum distance from groundwater": (Table 3). Some of the regulations (33, 38) place a general restriction on the disposal of toxic substances in greywater, providing examples of caustic substances considered to be toxic (e.g., hair dye and rags used for paintings). Some of the rules also recommend using only environmentally friendly cleaning products (38), and some even provide a list of products' ingredients or cite a source where such a list can be found (50).

Administrative Issues

Administrative mechanisms are, of course, a very important component of a strategy for ensuring extensive and safe utilization of greywater. Some states have chosen to issue a general permit for all household-scale greywater reuse schemes (33). Other states require permits for both specific greywater treatment units and for their installation (34). A description of permit requirements for different states is summarized by the tier approach (Table 5). In this approach, greywater use is divided according to different categories such as water volume and consumer type. Generally, more constraints are applied for larger reuse schemes. As administrative mechanisms become more complex, less people will choose to reuse greywater or comply with the promulgated rules. The result would be less than optimal water savings or, alternatively, the introduction of hazards from unauthorized use of greywater (because of the large number of households that might choose to utilize greywater, enforcement constitutes a particularly daunting task). On the other hand, excessively lenient regulations may jeopardize public and environmental health. An effective greywater policy must be based on clear risk levels and on an accessible and logical code of practice. Such an approach is starting to "percolate" into professional and public awareness, as evident from the risk assessment framework used in the WHO and the Australian guidelines (14, 15). However, a more thorough investigation into greywater risk assessment and management is required specifically for onsite reuse schemes.

Discussion

Greywater is comprised of very diverse components, making the drafting creation of comprehensive risk assessment, guidelines, and regulations a formidable task. Moreover, determining an acceptable risk for water reuse schemes will vary from place to place according to the severity of local water stress and the level of background risks as well as the existing "governance" in the water sphere and regulatory capacity. Quantitative methods, such as risk assessment, offer an important tool for identifying the most prominent risks that need to be addressed by greywater regulations. According to Ottoson and Stenstrom (18) these are primarily associated with the presence of viruses, which are more common in multihousehold greywater reuse schemes. Since in these schemes water is usually treated, the environmental risk may be less significant. In single household greywater reuse schemes in which water is not treated but restrictions are enforced, the most prominent risk may be environmental followed by microbial. Therefore, administratively, regulation of single household should be distinguished from multi-household schemes as the salient criteria for the level of treatment, rather than the volume of water per se. Moreover, the use of untreated greywater is not recommended at all times even for single households. In places where technical and administrative capacity is higher, it is essential to prescribe additional barriers, such as disinfection or more

advanced treatment, in order to provide a wider range of using options and to avoid unnecessary risks.

Exceptions to this rule may be in places where severe water stress exists and the marginal benefits of additional water sources are particularly high.

Where treatment is unavailable the exposure barriers should be decided according to the reuse scheme. For example, in a single household where untreated greywater is used, only subsurface diversion should be allowed. Using the common barriers such as in Table 3 can provide an adequate response for the health risks of onsite reuse. Additionally, it is recommended to exclude kitchen effluents as they may introduce third party pathogens, high organic loads, oil, grease, and detergents which might contaminate the environment.

Prevention of environmental harm must be considered prior to greywater reuse and should be integrated into relevant guidelines. Certain greywater sources are expected to contain higher loads of environmental hazards (such as Na and surfactants) than others (3). Therefore, choosing the right greywater source for irrigation can, in and of itself, reduce environmental risk. Moreover, adequate treatment can not only reduce health risks but also readily eliminate most potential environmental hazards (22, 39). Selective use of certain household chemicals and pharmaceuticals may also be an effective strategy for reducing associated environmental risks; however, this approach has not yet been adequately characterized. In order to assess the potential risk of the different environmental hazards, and the capability of a treatment system to reduce it to an acceptable level, we suggest the development of a framework according to the risk assessment principles detailed in this paper.

It should be noted that at present, millions of people are using greywater with little or no treatment, unaware of the potential harm their well-meaning activities may be causing. Risk-benefit calculations can help ensure that water recycling produces only de minimus health and environmental risks, while not unnecessarily interfering with society's ability to increase its water supply through cost-effective practices. Available information and accessible guidelines for the public must be disseminated in order to reduce the risks associated with greywater reuse, while taking advantage of its potential as an additional water resource.

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