Exploration of Possibility to Normalize Greywater Recycling in Malaysia

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UNIVERSITI SAINS MALAYSIA

Our Past Studies on Water Reuse

i) Strategic Planning of Urban Water Reuse Interventions for Community Resilience, Royal Academy of Engineering, £19,964.03, 03/08/2020-31/07/2021.

ii) IoT System for Water Reuse in Developing Cities, ICT Virtual Organization of ASEAN Institutes and NICT (ASEAN IVO), USD69,500.00, 1/4/2021-31/3/2023.

iii) Propagate Positive Impacts of IoT in Water Reuse through Frontiers, Frontiers Champions 2021, £10,000, 1/12/2021-31/1/2023.

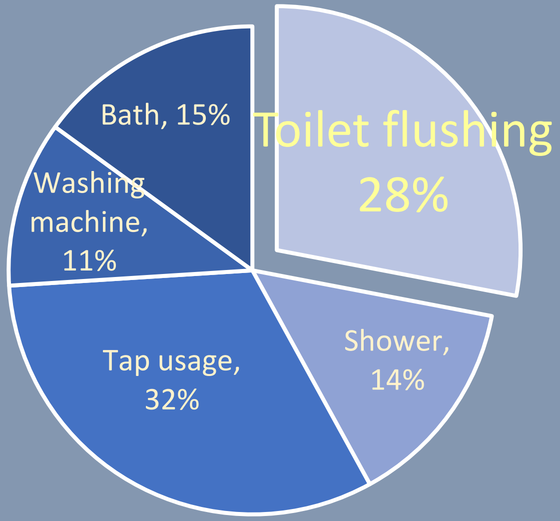
https://sites.google.com/view/frontierschampions2022/

Find out more about my works here!

Water reuse

Do we have enough water?

- Malaysians consume freshwater about 226 L/p/d (Thailand 90 L/p/d; Singapore 155 L/p/d)
- 43% of clean water turns into greywater after bath and hand washing.
- 30-40% of potable water can be saved by recycling greywater for toilet flushing or garden irrigation.



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LEADER LETTERS COLUMNISTS

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By Salleh Buang - December 15, 2020 @ 12:15am


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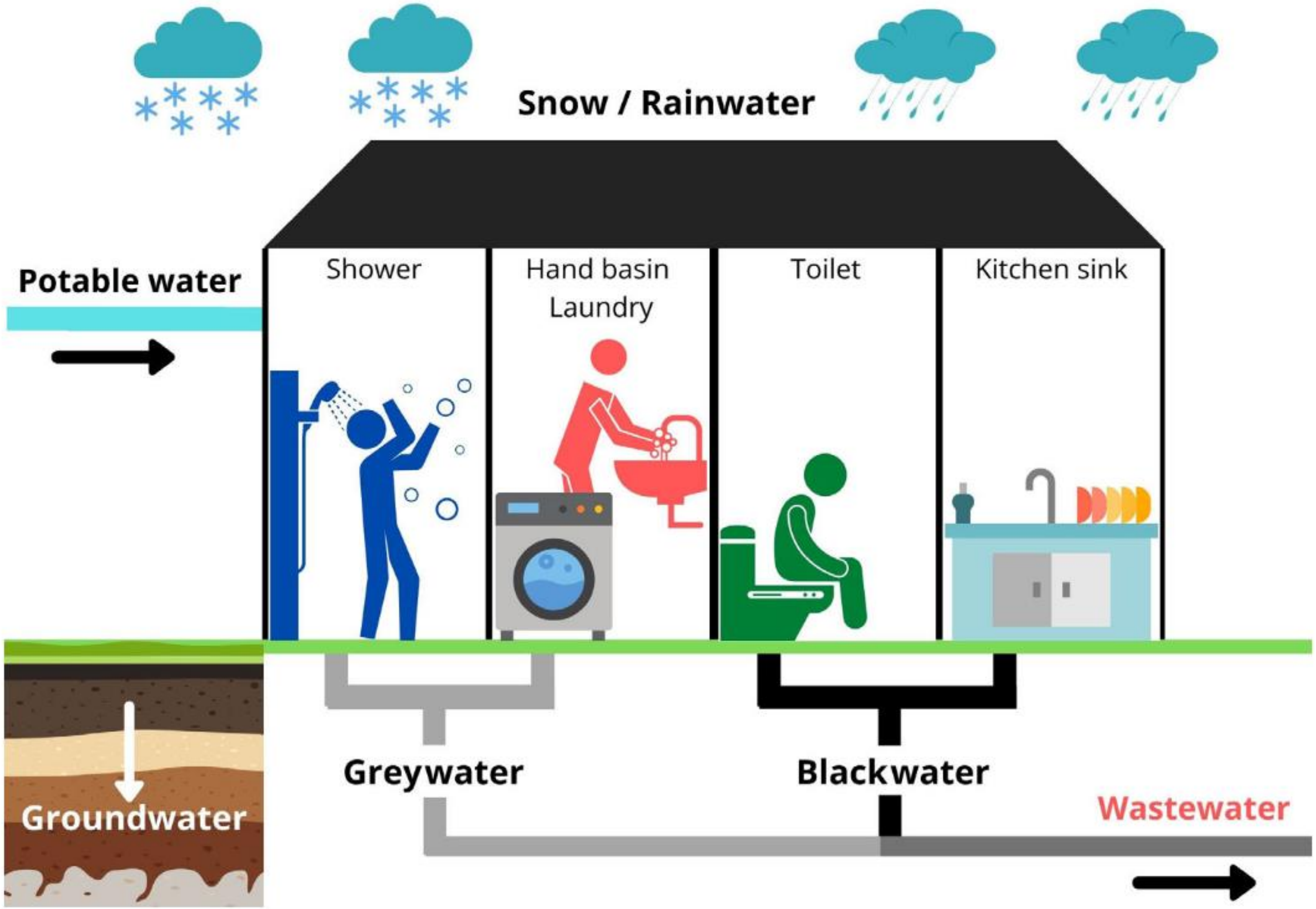

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How difficult to reuse water?

Regulatory requirements

Health risks

Public acceptance

Technology

Cost

Sustainability

Greywater treatment standard

Table 1
Treated greywater (for non-potable applications) standard in various countries.

	Unit	Australia	Israel	USA	Italy	New South Wales	UK	Canada
References		Chaillou et al. (2011) Australian Capital Territory (2004)	Chaillou et al. (2011) Ramona et al. (2004)	Couto et al. (2014), Chaillou et al. (2011), US EPA (2004)	Chaillou et al. (2011)	Couto et al. (2014); Leong et al. (2017)	Couto et al. (2014); Environment Agency (2011)	Couto et al. (2014) MHC (2010)
pH	–	–	–	6 to 9	6 to 9.5	–	5 to 9.5	–
TSS	mg/L	<30	<10	–	<10	<20	–	<20
Turbidity	NTU	–		<2	–	2	<10	<5
COD	mg/L	–	<100	–	<100	–	–	
BOD_5	mg/L	<20	<10	<10	<20	<20	–	<20
Total N	mg/L	–	–	–	<15	–	–	
Total P	mg/L	–	–	–	<2	–	–	
Cl_2 residual	mg/L	–	–	>1	–	2	<2	>0.5
E. coli	cfu/100 mL	–	–	–	<10	–	–	–
Thermotolerant coliforms	cfu/100 mL	<10	–	–	–	–	–	–
Faecal coliforms	cfu/100 mL	–	–	N.D	–	<1	1000	<200
Salmonella	cfu/100 mL	–	–	–	N.D	–	–	–
Type of reuse	–	Surface irrigation, toilet flushing, laundry use, car washing	–	Landscape irrigation, toilet flushing, fire protection, commercial air conditioning	–	Toilet flushing	Toilet flushing	Toilet flushing

https://www.sciencedirect.com/science/article/pii/S0959652617322710

Water Reuse standard Malaysia

http://www.nahrim.gov.my/

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	μS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	ppt	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
Total Dissolved Solid	mg/l	500	1000				
Total Suspended Solid	mg/l	25	50				
Temperature	°C	-	Normal + 2 °C				
Turbidity	NTU	5	50				
Faecal Coliform**	count/100 ml	10	100				
Total Coliform	count/100 ml	100	5000				

Notes :

N : No visible floatable materials or debris, no objectional odour or no objectional taste
* : Related parameters, only one recommended for use
** : Geometric mean
a : Maximum not to be exceeded

WATER CLASSES AND USES

CLASS	USES
Class I	Conservation of natural environment. Water Supply I – Practically no treatment necessary. Fishery I – Very sensitive aquatic species.
Class IIA	Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species.
Class IIB	Recreational use with body contact.
Class III	Water Supply III – Extensive treatment required. Fishery III – Common, of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above.

ANNEX

NATIONAL WATER QUALITY STANDARDS FOR MALAYSIA

PARAMETER	UNIT	CLASS				
		I	IIA/IIB	III#	IV	V
Al	mg/l	NATURAL LEVELS OR ABSENT	-	(0.06)	0.5	LEVELS ABOVE IV
As	mg/l		0.05	0.4 (0.05)	0.1	
Ba	mg/l		1	-	-	
Cd	mg/l		0.01	0.01* (0.001)	0.01	
Cr (VI)	mg/l		0.05	1.4 (0.05)	0.1	
Cr (III)	mg/l		-	2.5	-	
Cu	mg/l		0.02	-	0.2	
Hardness	mg/l		250	-	-	
Ca	mg/l		-	-	-	
Mg	mg/l		-	-	-	
Na	mg/l		-	-	3 SAR	
K	mg/l		-	-	-	
Fe	mg/l		1	1	1 (Leaf) 5 (Others)	
Pb	mg/l		0.05	0.02* (0.01)	5	
Mn	mg/l		0.1	0.1	0.2	
Hg	mg/l		0.001	0.004 (0.0001)	0.002	
Ni	mg/l		0.05	0.9*	0.2	
Se	mg/l		0.01	0.25 (0.04)	0.02	
Ag	mg/l		0.05	0.0002	-	
Sn	mg/l		-	0.004	-	
U	mg/l		-	-	-	
Zn	mg/l		5	0.4*	2	
B	mg/l		1	(3.4)	0.8	
Cl	mg/l		200	-	80	
Cl_2	mg/l		-	(0.02)	-	
CN	mg/l		0.02	0.06 (0.02)	-	
F	mg/l		1.5	10	1	
NO_2	mg/l		0.4	0.4 (0.03)	-	
NO_3	mg/l		7	-	5	
P	mg/l		0.2	0.1	-	
Silica	mg/l		50	-	-	
SO_4	mg/l		250	-	-	
S	mg/l		0.05	(0.001)	-	
CO_2	mg/l		-	-	-	
Gross-α	Bq/l		0.1	-	-	
Gross-β	Bq/l		1	-	-	
Ra-226	Bq/l		< 0.1	-	-	
Sr-90	Bq/l		< 1	-	-	
CCE	μg/l		500	-	-	-
MBAS/BAS	μg/l		500	5000 (200)	-	-
O & G (Mineral)	μg/l		40; N	N	-	-
O & G (Emulsified Edible)	μg/l		7000; N	N	-	-

CO_2	mg/l		-	-	-	
Gross-α	Bq/l		0.1	-	-	
Gross-β	Bq/l		1	-	-	
Ra-226	Bq/l		< 0.1	-	-	
Sr-90	Bq/l		< 1	-	-	
CCE	μg/l		500	-	-	-
MBAS/BAS	μg/l		500	5000 (200)	-	-
O & G (Mineral)	μg/l		40; N	N	-	-
O & G (Emulsified Edible)	μg/l		7000; N	N	-	-
PCB	μg/l		0.1	6 (0.05)	-	-
Phenol	μg/l		10	-	-	-
Aldrin/Dieldrin	μg/l		0.02	0.2 (0.01)	-	-
BHC	μg/l		2	9 (0.1)	-	-
Chlordane	μg/l		0.08	2 (0.02)	-	-
t-DDT	μg/l		0.1	(1)	-	-
Endosulfan	μg/l		10	-	-	-
Heptachlor/Epoxide	μg/l		0.05	0.9 (0.06)	-	-
Lindane	μg/l		2	3 (0.4)	-	-
2,4-D	μg/l		70	450	-	-
2,4,5-T	μg/l		10	160	-	-
2,4,5-TP	μg/l		4	850	-	-
Paraquat	μg/l		10	1800	-	-

Notes :
* = At hardness 50 mg/l $CaCO_3$
# = Maximum (unbracketed) and 24-hour average (bracketed) concentrations
N = Free from visible film sheen, discolouration and deposits

Treated Greywater Monitoring

Table 2-4 Quality monitoring requirements in Texas

Texas Category	Is human contact likely?	Examples	Monitoring frequency	*Enterococci* (MPN/100mL)	Fecal Coliforms or *E. coli* (MPN/100mL)	$CBOD_5$ or BOD_5 (mg/L)	Turbidity (NTU)
Type I	Yes	Irrigation, recreational impoundments, firefighting, toilet flush water	Twice weekly	9/4[1]	75/20[1]	5	3
Type II	No	Restricted or remote reuse	Once weekly	35	800/200[1]	15 or 20[2]	N/A

[1] The first value represents a single sample maximum value and the next value refers to a 30-day average (BOD5 and Turbidity) or 30-day geometric mean (fecal coliform or *E. coli*).

[2] In Type II uses, the CBOD5 maximum 30-day average value is 15 mg/L while the BOD5 value is 20 mg/l for the same period.

https://www.epa.gov/sites/production/files/2019-08/documents/2012-guidelines-water-reuse.pdf

Greywater Quality

Safe to be reused without treatment?

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Colour	TCU	15	150	150	-	-	-
Electrical Conductivity*	μS/cm	1000	1000	-	-	6000	-
Floatables	-	N	N	N	-	-	-
Odour	-	N	N	N	-	-	-
Salinity	ppt	0.5	1	-	-	2	-
Taste	-	N	N	N	-	-	-
Total Dissolved Solid	mg/l	500	1000	-	-	4000	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
Temperature	°C	-	Normal + 2 °C	-	Normal + 2 °C	-	-
Turbidity	NTU	5	50	50	-	-	-
Faecal Coliform**	count/100 ml	10	100	400	5000 (20000)[a]	5000 (20000)[a]	-
Total Coliform	count/100 ml	100	5000	5000	50000	50000	> 50000

objectional odour or no objectional taste
led for use

Greywater quality parameters	Countries					
	Americas	Oceania	Europe	Middle-East	Asia	Africa
Turbidity (NTU or ⁺FTU)	34–100	—	93⁺	15–58	196–225	270
TSS (mg/L)	19–156	0.5–795	11–319	45–155	55–619	180–537
Nitrates (mg/L)	0.11	—	—	0.70	1.49–40	4.26–8.43
TN (mg/L)	4.3–50.3	—	0.5–15.0	10.6–24.1	29.7–41.2	17
TP (mg/L)	0.5–5.3	—	0.1–187	1.4–12	1.0–5	2.3–61
BOD (mg/L)	45–144	3–380	208–1363	335–568	5–445	204–350
COD (mg/L)	205–600	—	390–2072	380–1171	89–643	644–848
Total coliforms (MPN[a] or CFU[b]/100 ml)	4.0×10^5–7.6×10^6[b]	4.4×10^2–3.7×10^8[b]	—	0–2.3×10^1[a]	—	3.8×10^6[b]
E. coli (CFU[b]/100 ml)	7.0×10^2–5.06×10^4[b]	5.0–8.6×10^3[b]	—	1.1×10^4[b]	—	1.8–2.4×10^4[b]
References	Zavala et al. (2016); Chrispim and Nolasco (2017); Palmarin and Young (2019); Goncalves et al. (2021)	Leonard et al. (2016)	Noutsopoulos et al. (2018); Sievers and Londong (2018); Jabri et al. (2019); Truu et al. (2019)	Abdel-Shafy et al. (2019); Oktor and Celik (2019); Alrousan and Dunlop (2020); Ucevli and Kaya (2021)	Deng et al. (2020); Perdana et al. (2020); Subramanian et al. (2020)	Oteng-Peprah et al. (2018); Dwumfour-Asare et al. (2020); Raphael et al. (2020)

https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1588

Greywater Treatment

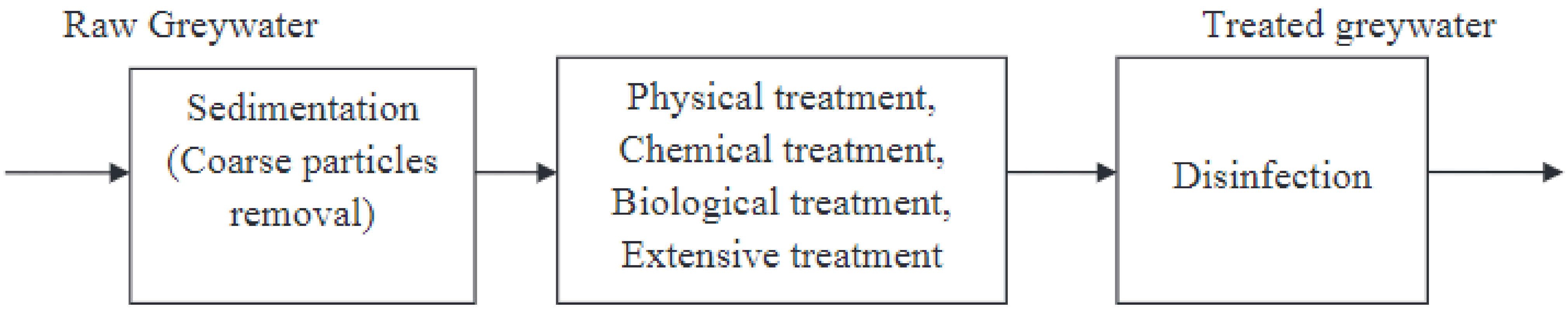

Fig. 3. Flow of greywater treatment.

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Table 2
Disinfection technologies and the microorganism indicator in greywater.[a]

	Operating conditions	Influent						Effluent						Removal efficiency	References
		E. C[b]	T.C[c]	HPC[d]	F.C[e]	S.A[f].	P.A[g]	E. C[b]	T.C[c]	HPC[d]	F.C[e]	S.A[f].	P.A[g]		
UV light disinfection	UV: λ = 254 nm; lamp intensity: 250 m J cm^{-2}; Greywater flow rate: 2.4 m^3/d	4.64×10^0	–	–	–	1.58×10^2	1.58×10^2	N.D	–	–	–	1.26×10^1	2.00×10^1	–	Benami et al. (2015)
UV light disinfection	UV: λ = 254 nm; lamp intensity: 2.8 mV s cm^{-2}; Greywater flow rate: 0.036 m^3/d –2.16 m^3/d	–	–	–	–	–	–	–	–	–	–	–	–	100% E.coli	do Couto et al. (2013)
UV light disinfection	UV: 36 W; lamp intensity: 69m W cm^{-2}; Greywater flow rate: 0.28 m^3/d	–	–	1.8×10^5	3.8×10^1	2.4×10^1	5.3×10^3	–	–	$> 10^5$	<10	<10	$> 10^3$	–	Friedler and Gilboa (2010); Friedler et al. (2011)
Recirculated vertical flow bioreactor	Filters: Layers of diameter 1.5 cm and 3–4 cm lime pebbles, 0–6 mm and 3–6 mm zeolites	3.10×10^4–4.1×10^5	6.2×10^4 –3.85×10^6	–	–	–	–	–	–	–	–	–	–	Up to 90% total coliforms; Up to 99.5% E. coli	Ammari et al. (2014)
Photocatalytic Photon-fenton	UV: λ = 254 nm, 150 ppm H_2O_2/UV	–	–	–	–	–	4.7×10^4 MPN/100 mL	–	–	–	–	–	0	–	Teodoro et al. (2014)
Solar disinfection (SODIS)	Solar: 518 W/m^2, Batch system of HRT: 24 h	2.0×10^4–6.6×10^5 MPN/100 mL	8.2×10^6 -8.7×10^8 MPN/100 mL	–	–	–	–	5.29×10^4–1.48×10^2 MPN/100 mL	Not reported	–	–	–	–	–	Pansonato et al. (2011)
Solar disinfection (SODIS)	Solar: 518 W/m^2, Continuous system of 24 h	N.D	5.4×10^1–1.2×10^2 MPN/100 mL	–	–	–	–	N.D	<1–3.7×10^1 MPN/100 mL	–	–	–	–	–	Pansonato et al. (2011)
Chlorination	Hypochlorite: 0.5 mg/L, HRT: 0.5 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	5.8×10^2	2.1	1×10^{-1}	4×10^1	–	Friedler et al. (2011)
	Hypochlorite: 0.5 mg/L, HRT: 3 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	7.2×10^2	0.8×10^{-1}	4×10^{-1}	2.9×10^1	–	Friedler et al. (2011)
	Hypochlorite: 0.5 mg/L, HRT: 6 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	4.4×10^2	3×10^{-1}	0	3.1×10^1	–	Friedler et al. (2011)
Chlorination	Hypochlorite: 1 mg/L, HRT: 0.5 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	5.6×10^2	2	0	1.8×10^1	–	Friedler et al. (2011)
	Hypochlorite:	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	3.8×10^2	3	1×10^{-1}	8	–	Friedler

									100 mL						
Chlorination	Hypochlorite: 0.5 mg/L, HRT: 0.5 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	5.8×10^2	2.1	1×10^{-1}	4×10^1	–	Friedler et al. (2011)
	Hypochlorite: 0.5 mg/L, HRT: 3 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	7.2×10^2	0.8×10^{-1}	4×10^{-1}	2.9×10^1	–	Friedler et al. (2011)
	Hypochlorite: 0.5 mg/L, HRT: 6 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	4.4×10^2	3×10^{-1}	0	3.1×10^1	–	Friedler et al. (2011)
Chlorination	Hypochlorite: 1 mg/L, HRT: 0.5 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	5.6×10^2	2	0	1.8×10^1	–	Friedler et al. (2011)
	Hypochlorite: 1 mg/L, HRT: 3 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	3.8×10^2	3×10^{-1}	1×10^{-1}	8	–	Friedler et al. (2011)
	Hypochlorite: 1 mg/L, HRT: 6 h	–	–	1.1×10^6	1.5×10^2	9.8	3.8×10^2	–	–	1.5×10^{-2}	0	0	3.6	–	Friedler et al. (2011)
	Hypochlorite: 5–10 mg/L, HRT – 36 s	4.64×10^0	–	–	–	1.58×10^2	1.58×10^2	N.D	–	–	–	3.98×10^0	1.58×10^0	–	Benami et al. (2015)
Hydrogen peroxide plus (HPP)	Concentration: 125 mg/L, contact time: 35 min	–	–	–	9×10^1–3×10^5	–	–	–	–	–	–	–	–	99% Faecal coliform	Ronen et al. (2010)
Hydrogen peroxide	Concentration: 1 mL/L greywater	–	8.13 log		–	–	–	–	6.60 log	–	–	–	–	96.99%	Teh et al. (2015)
Electro-coagulation + disinfection	1 M NaCl, 1 M H_2SO_4, system conductivity: 500–600 µS/cm, effective electrode area: 1000 cm^2, contact time: 70 s, Greywater flowrate: 1.2–1.4 m^3/hr,	3.5×10^2–5.6×10^2	–	–	–	–	–	N.D	–	–	–	–	–	–	Lin et al. (2005)
Ultrafiltration and Reverse Osmosis membrane	5 m^3/hr hand basin greywater (mixed with 11.7 m^3/hr groundwater and 4.2 m^3/hr rainwater)	10^5 to 10^6	–	–	–	–	–	N.D	–	–	–	–	–	–	Birks et al. (2004)

[a] In CFU/100 mL, otherwise stated.
[b] *Escherichia coli*.
[c] Total coliforms.
[d] Heterotrophic plate counts.
[e] Faecal coliform.
[f] *Staphylococcus aureus*.
[g] *Pseudomonas aeruginosa*.

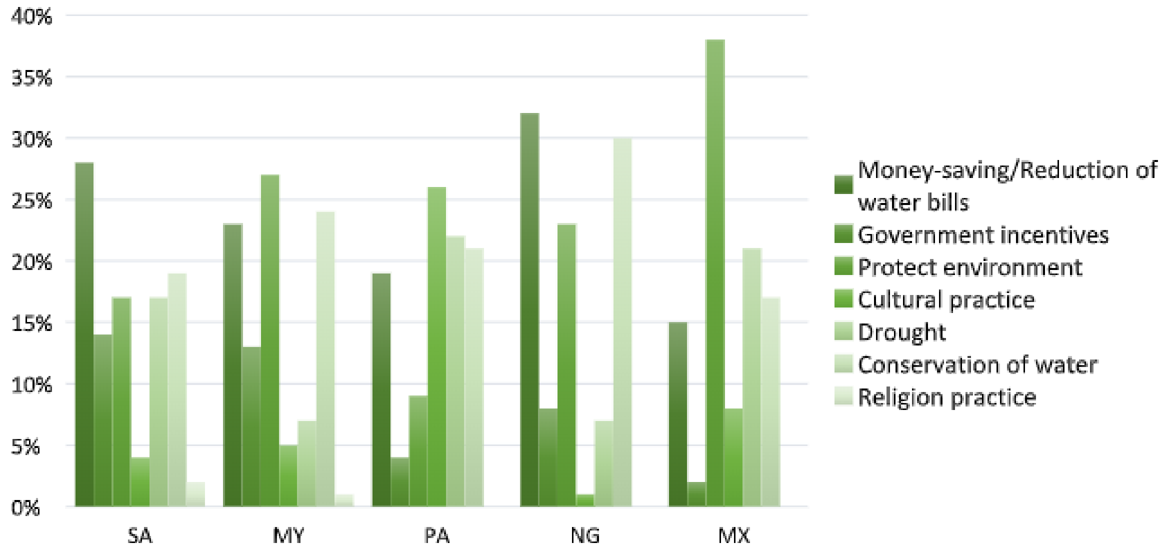
https://www.sciencedirect.com/science/article/pii/S0959652617322710

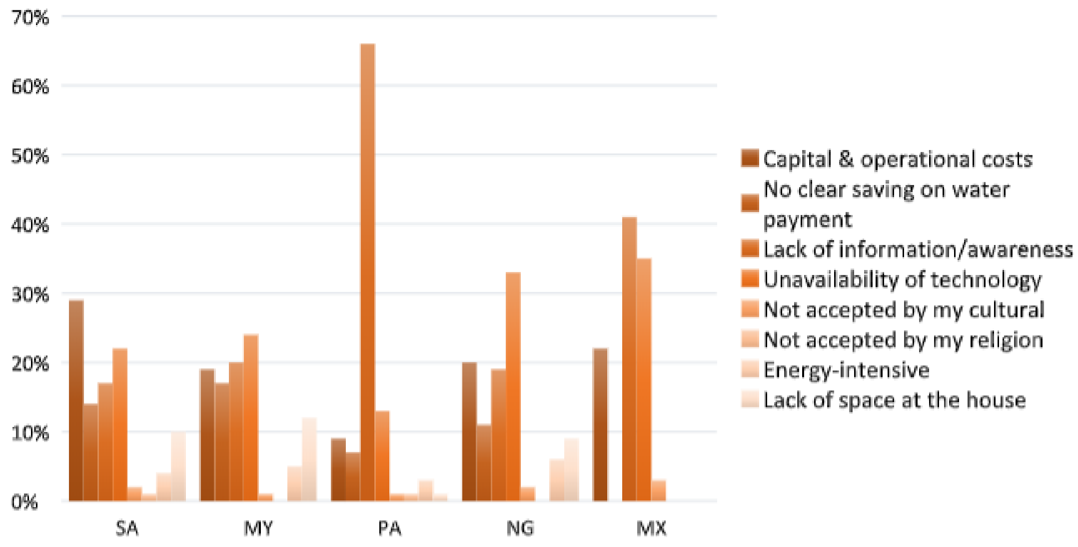
Public Acceptance

Causality between challenges, motivations, and extent of use of water recycling systems in residential properties

- Challenges and extent of the use of water recycling systems in
- residential properties were studied in Malaysia, Mexico, Nigeria, Panama, and South Africa.
- Micro-challenges in the implementation of water reuse in residential properties.
- ✓ the lack of space
- ✓ no clear savings on water payment
- ✓ lack of information/awareness
- Our study deduces improving water recycling systems efficiency can reduce these micro-challenges.
- The extent of water reuse in residential properties will increase with public awareness and education.
- The acquisition of the basic environmental and technical knowledge associated with water recycling and the government incentive for implementing water recycling systems in residential properties were recommended in the study.
- The findings helped to develop a data-driven decision-making framework to build capacity for the analysis of new water reuse intervention strategies commensurate with the capabilities and resources of
- urban authorities and communities.

Motivation and Challenges in Water Reuse.





Let me get your view

https://miro.com/welcomeonboard/bnk0RUx0SVNGaklITHZ3YVhlT2dmNHBqNU1Sd0M1SXc4MGpUbXVTdzZSbWc3MUxDc3pIcnBvQnAzTVdOTk9FdHwzNDU4NzY0NTE3NDM1NjQ2NzYx?share_link_id=15208520112

What stops you from reuse water?

What encourages you to reuse water?