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Microbial quality of untreated stormwater in Australian catchments: human health perspectives

Jane-Louise Lampard, Jatinder Sidhu, Míriam Agulló-Barceló, Eloise Larsen, Wolfgang Gernjak

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Microbial quality of untreated stormwater in Australian catchments: human health perspectives
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Authors
Ms Jane-Louise Lampard, School of Health and Sports Sciences, University of the Sunshine Coast, Australia
jlampard@usc.edu.au

Dr Jatinder Sidhu, CSIRO Land and Water, Australia

Dr Míriam Agulló-Barceló, Advanced Water Management Centre, The University of Queensland, Australia

Dr Eloise Larsen, Advanced Water Management Centre, The University of Queensland, Australia

Dr Wolfgang Gernjak, Catalan Institute for Water Research, Spain, Advanced Water Management Centre, The University of Queensland, Australia

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Cooperative Research Centre for Water Sensitive Cities
Level 1, 8 Scenic Blvd, Clayton Campus
Monash University
Clayton, VIC 3800

p. +61 3 9902 4985
e. admin@crcwsc.org.au
w. www.watersensitivecities.org.au

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Overview

Reusing stormwater runoff can improve water security by reducing demand for ground water and potable water supplies. Whilst the number of stormwater harvesting schemes in Australia is increasing, the full potential of stormwater as an alternate water source is yet to be realised. Understanding the range of chemicals and microorganisms likely to be present in untreated stormwater will assist stormwater managers to maximise the potential of this water resource in a manner that is protective of human and environmental health.

Introduction

Existing knowledge of microbial health risks inherent in Australian stormwater focuses on exposure via ingestion, and the resultant risk of gastrointestinal illness. To date, data sets comprise faecal indicator organisms, enteric bacteria, protozoa and viruses and human genetic biomarkers. Implementation of stormwater harvesting and reuse schemes in Australia has increased the likelihood of human exposure and necessitated further research into health risks associated with multiple exposure routes. This is particularly relevant given the majority of existing Australian schemes involve non-potable reuse where exposure can be considered equally or more likely to occur via inhalation or dermal contact than via ingestion.

Samples of untreated urban stormwater runoff (n=94) were collected during rainfall events at 10 diverse urban catchments across Australia, and analysed to identify chemical and microbial hazards to human health. While this report focuses on the microbial hazards in stormwater, chemical and toxicological water quality results are presented and discussed in a separate CRCWSC Industry Report *Characterisation of Chemical Hazards in Stormwater*, supported by the CRCWSC Stormwater Quality Database.

The catchments in Queensland (QLD), New South Wales (NSW), Victoria (VIC) and Western Australia (WA) represent commercial, industrial and residential land uses in temperate, sub-tropical and Mediterranean style climates, respectively (Table 1). Samples were collected from within stormwater drains, waters that receive stormwater, and at the inlets to wetland treatment systems, to be representative of the broad range of capture locations that may be utilised for stormwater reuse schemes. The majority of samples were composite event mean concentration samples (n=88), with the exception being Western Australian samples that were grab samples (n=6).

The range of microorganisms chosen to monitor in this study were identified through literature review, and in consultation with experts such as microbiologists and water-related health risk assessors so that each of the three exposure routes were represented. Six pathogens (Table 2) were selected based on three criteria: potentially present in Australian stormwater; significant burden of disease associated with infection; and a validated dose-response model exists for the pathogen. Faecal indicator bacteria (FIB) were included as reference organisms. Human adenovirus, polyomavirus and *Bacteroides* HF183, found in high concentrations in wastewater, were selected as human specific biomarkers for use as indicators of human sewage ingress.

Analytical methods used to detect the selected microorganisms are detailed in Sidhu et al. (2012, 2013). Briefly, pathogenic microorganisms and biomarkers were detected in a qualitative manner (presence/absence) using molecular-based methods (polymerase chain reaction), whereas FIB were enumerated using culture-based methods.

Table 1. Summary of catchment characteristics

State	Catchment	Predominant land use	Total sampling events	Climate	Total area (ha)
NSW	Hornsby	Commercial	10	Temperate	1.08
NSW	Ku-ring-gai	Residential	5	Temperate	8.8
NSW	Blackman Swamp Creek, Orange	Residential/Commercial	6	Temperate	3,417
QLD	Fitzgibbon	Peri-urban residential	12	Sub-tropical	290
QLD	Makerston St	Commercial	20	Sub-tropical	49
VIC	Banyan	Residential	10	Temperate	235
VIC	Industrial	Industrial	7	Temperate	20
VIC	Smith St	Commercial	9	Temperate	10
WA	Vertu	Residential	2	Mediterranean	nd
WA	Anvil	Industrial	4	Mediterranean	1,200

nd = not determined

Table 2. Pathogens monitored in urban stormwater

Pathogen	Name	Reservoirs/ transport hosts	Transmission Route	Health outcome
Bacteria	*Legionella pneumophila*	Aquatic environments, soil, free living protozoa	Inhalation	Respiratory illness (pneumonia, Pontiac fever)
	Staphylococcus aureus	Humans, soil, domestic and wild animals	Dermal contact	Skin, eye, ear infections, septicaemia
	Campylobacter spp., *C. jejuni*	Humans, domestic and wild animals	Ingestion	Gastroenteritis, Guillain–Barré syndrome
	Salmonella	Aquatic environments, soil, humans, domestic and wild animals	Ingestion	Gastroenteritis, reactive arthritis
Viruses	Adenovirus	Humans, sewage	Ingestion, Inhalation, Dermal contact	Gastroenteritis, respiratory illness, eye infections

Microbial water quality results

The presence of waterborne pathogens, human biomarkers and faecal indicators varied notably across catchment sites and amongst stormwater events within the same catchment (Table 3). *Campylobacter spp.,* found at seven of the ten sites, was the most frequently detected microorganism present in 73% of samples analysed. Not all strains of *Campylobacter spp.* are pathogenic to humans, as such the presence of human pathogen *C. jejuni* was investigated in a sub-set of samples from nine sites. Positive detections of *C. jejuni* were observed in only 6% of samples with all detections occurring in the same residential catchment. Adenovirus and *Salmonella* exhibited the highest variability across sites, ranging from non-detection at some sites to detections in 100% of samples per site. Adenovirus, detected at 70% of sites and 51% of total samples, had the broadest distribution across Australia with high variability in incidence per site. While it was detected in 100% of samples from two sites (Fitzgibbon n=5 and Smith St n=9), Adenovirus was not detected at three other sites (n=3, n=2 and n= 4, respectively). Interestingly, Adenovirus was only detected where stormwater pH was less than 7. *Salmonella* spp. which was found at under half of the sites (40%) and in one quarter of total samples (26%) was also detected in 100% of samples from one site (Fitzgibbon n= 5). *Staphylococcus aureus* was detected at 66% of sites but less frequently per sample (average, 22%), whereas *Legionella pneumophila* was not detected in any samples (n=39) from the eight sites investigated across the four states (QLD, NSW, VIC and WA).

Overall, the marker for human-specific *Bacteroides* HF183 was detected at 66.7% of sites sampled across the nation (n=9), and *Human Polyomavirus* at 71.4% of sites (n=7) sampled in QLD, NSW and VIC. The presence of genome copies of these human-specific markers in stormwater indicates human faecal contamination. Detections of these biomarkers at sites where chemicals such as caffeine, acesulfame-K and mestranol (Gernjak et al., 2017) have also been detected suggests sewage contamination of stormwater occurs more commonly than anticipated in these catchments with separate storm sewer systems. This is in agreement with previous reported sewage contamination in stormwater across Australian sites (Sidhu et al., 2013). Sewer ingress, sewer overflows or flushing of pathogens from nearby areas during storm events are likely sources. At the time of sampling sewerage infrastructure in the catchments in QLD, NSW and VIC ranged in age from approximately 40-110 years old with the oldest sewered circa 1900 and the youngest, circa 1973. Sewerage infrastructure in one of the WA catchments (Vertu) was 7-8 years old and the second catchment (Anvil) had drainage infrastructure in place but no deep sewer connection.

Faecal indicator bacteria (FIB), *Escherichia coli* (*E. coli*) and *Enterococci*, were consistently detected in all stormwater samples from all catchments (Table 3) with high inter- and intra-site variability. All samples contained $\geq$10 CFU (1 log) *E. coli* per 100mL, and up to four orders of magnitude above this value (Table 3). Lowest *E. coli* counts were observed in a WA catchment that was undergoing residential development (Vertu, 10 per 100mL) and a NSW central business district (CBD) precinct (40 per 100mL). Highest *E. coli* counts were observed in a QLD CBD precinct (2.4 x10^5 per 100mL) and VIC residential catchment (1.6 x10^5 per 100mL). Lowest *Enterococci* counts occurred in the two WA catchments. Of interest, the minimum count in the industrial development with no deep sewer connection was higher than in the new residential catchment, albeit both were within one log order (63 per 100mL and 20 per 100mL, respectively). Highest *Enterococci* counts were seen in commercial and residential catchments in VIC (1.5 x10^5 per 100mL and 1.0 x10^5 per 100mL respectively). Importantly, <10 CFU *E. coli* per 100mL represents the guideline value for median *E. coli* numbers during routine operation of a stormwater scheme intended for irrigation (NRMMC, EPHC, & NHMRC 2009).

Faecal indicator bacteria counts and detections of pathogens were notably lower at WA sites when compared to others and the human specific biomarker HF183 was detected in the absence of either Polyomavirus or Adenovirus. It is difficult to attribute specific reasons due to the limited number of samples taken for WA, which had the lowest number of sampling events of all states i.e. 6 (Table 1). Additionally, in contrast to other samples, WA samples were grab samples and therefore representative of a snapshot in time within an event rather than a mean concentration across the hydrograph of the event as with other sites. Further, due to methodological restraints, the volume of sample analysed by PCR for pathogens and biomarkers was 1L rather than the 10L measured from other sites which may have led to under-detection for these samples.

Table 3. Pathogens, human biomarkers and faecal indicators detected in Australian stormwater

		Positive detections																cfu or MPN per 100mL			
		Pathogens												Human biomarkers				Faecal indicators			
State	**Catchment**	**Adenovirus**		***Campylobacter* spp.**		***C. jejuni***		***Legionella pneumophila***		***Salmonella***		***S. aureus***		**Polyomavirus**		***Bacteroides* HF183**		***E. coli***		**Enterococci**	
		n	**% +**	**n**	**% +**	**n**	% +	**n**	**% +**	n	% +	n	% +	n	% +	n	% +	n	Mean log	n	Mean log
NSW	Hornsby	9	88.9	9	55.6	6	0	*	*	9	44.4	6	0	9	77.8	*	*	9	3.1	9	4.1
	Ku-ring-gai	4	25	2	50	3	0	2	0	4	0	3	0	2	0	3	66.6	3	3.3	3	3.7
	Orange	6	50	2	100	6	0	4	0	6	0	6	16.7	2	50	4	50	2	4.1	2	4.3
QLD	Fitzgibbon	5	100	1	0	*	*	*	*	5	100	*	*	5	60	5	0	5	3.4	5	3.7
	Makerston	17	23.5	4	100	3	0	16	0	17	17.6	6	66.7	4	75	17	17.6	7	4.0	7	3.7
VIC	Banyan	10	50	6	66.7	7	42.9	7	0	10	40	7	14.3	6	66.7	7	85.7	7	3.7	6	3.8
	Industrial	3	0	*	*	3	0	3	0	3	0	3	0	*	*	3	0	3	2.8	3	3.0
	Smith St	9	100	9	88.9	1	0	1	0	1	0	1	0	1	0	1	100	5	3.7	5	4.6
WA	Vertu	2	0	*	*	2	0	2	0	2	0	*	*	*	*	2	50	2	1.0	2	2.97
	Anvil	4	0	*	*	4	0	4	0	4	0	*	*	*	*	4	0	4	2.2	4	1.9
		n	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**	**n**	**% +**
Total samples		69	50.7	33	72.7	48	6.3	39	0	61	26.2	32	18.8	29	58.6	46	32.6	47	100	46	100

n = number of samples, % + = percentage of positive detections at site, * = not tested, *C. jejuni* = *Campylobacter jejuni*, *S. aureus* = *Staphylococcus aureus*, *E. coli* = *Escherichia coli*, CFU = colony forming units; MPN = most probable number.

Conclusion

The microbial quality of stormwater was observed to vary both between site-specific events, as well as between sites, with few determinable patterns. The data collected in this national investigation into the microbial quality of stormwater demonstrates that treatment is required to manage the health risks associated with stormwater harvesting schemes. Water quality risks associated with stormwater from these catchments arise mostly from pathogens likely to result from sewage ingress into stormwater. This finding is supported by results of chemical and toxicological analyses conducted on stormwater sampled from the same sites that demonstrate the presence of chemicals or toxic effects associated with chemicals present in human sewage (Sidhu et al, 2013; Tang et al. 2013; Gernjak et al. 2017). To protect human health, appropriate treatment of stormwater is recommended prior to use. The level of treatment required for a given use will be site and end use dependent, and pre-characterisation of stormwater quality at each site is recommended. Guidance for the pre-characterisation and treatment of stormwater for safe supply in non-potable reuse applications is outlined in the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Stormwater Harvesting and Reuse* (NRMMC, et al., 2009). For potable reuse application, treatment is required to meet the *Australian* Guidelines *for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies* (NRMMC, et al., 2008).

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Level 1, 8 Scenic Boulevard
Monash University
Clayton VIC 3800

info@crcwsc.org.au

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