Institution: University of Bath

Unit of Assessment: A8 Chemistry

Title of case study: Wastewater-Based Epidemiology for environmental and public health assessment

Period when the underpinning research was undertaken: 2010 - 2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof Barbara Kasprzyk-Hordern	Professor, previously Reader, Senior Lecturer, Lecturer	September 2010 - present
Mr Bruce Petrie	Research Associate	October 2013 - October 2016
Dr Luigi Lopardo	Research Associate	October 2017 - September 2018
Dr Erika Castrignanò	Research Associate	July 2016 - May 2018
Dr Kathryn Proctor	Research Associate	October 2019 - present

Period when the claimed impact occurred: 2014 – 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Current public health monitoring systems cannot provide real time and comprehensive information on community health. Wastewater based epidemiology (WBE) offers a solution, providing real-time long-term spatiotemporal datasets on public and environmental health and risks. Using University of Bath research in environmental analytical chemistry, a novel diagnostic approach, urban water fingerprinting, has been established to conduct WBE, impacting health, wellbeing and the environment:

1. Adoption of WBE by the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) in 2016 to estimate spatiotemporal trends of illicit drug usage; this feeds into their Europe-wide evidence based early warning system;

2. Adoption of a WBE-based Water fingerprinting platform by Wessex Water (WW), major water supplier with 2,800,000 customers, changing their operations to mitigate environmental health impact, including a GBP1,000,000 investment by WW to monitor public and environmental health risks including SARS-CoV-2 surveillance.

2. Underpinning research

Rapid assessment of public and environmental health is essential for the prevention, control or mitigation of exposure risks as well as improving our population's health. This includes exposure to chemicals (e.g. illicit drug usage and industrial chemical exposure) and biological risks (e.g. pathogens such as SARS-CoV-2). Current epidemiology approaches (such as molecular epidemiology) are limited in scope due to logistical difficulties and high cost, the restricted size of study groups and inability to gather comprehensive information on combined spatiotemporal exposure to mixtures of stressors and their effects. Therefore, the

community lacks robust measures to gather real-time information on community-wide exposure and resulting disease.

There is a need for an evidence-based public health risk prediction system, to collate long-term spatiotemporal datasets on public health status and trigger rapid response from regulatory and public health sectors that can prevent disease and promote environmental health. Such a system can allow public health threats to be identified rapidly, at low cost, and instantly dealt with, reducing the global burden on public health. Professor Kasprzyk-Hordern's research at University of Bath in environmental and analytical chemistry has made major contributions to the development of a new diagnostic technology, urban water fingerprinting, to conduct wastewater-based epidemiology (WBE), providing a revolutionary solution that has gained wide adoption.

Urban water fingerprinting, a cutting edge approach of extracting epidemiological information, has been developed as a key part of WBE, to provide anonymised, comprehensive and objective information on the health status of populations and surrounding environments in real time. WBE was developed in a strong cross-sectoral and transdisciplinary collaborative research initiative within the Sewage Analysis CORe group Europe (SCORE), and EU SEWPROF project (2012-16) which was led by Professor Kasprzyk-Hordern.

Since 2010, Professor Kasprzyk-Hordern has made key research contributions to the development of WBE and water fingerprinting via:

(i) Development of bioanalytical methods followed by comprehensive research on the fate and effects of emerging contaminants in the UK environment (especially South West) (1), yielding one of the most comprehensive aqueous environment profiling studies in the UK (2).

(ii) Development of new fingerprinting approaches including a new tool for WBE biomarker discovery (3) utilising high resolution mass spectrometry, suspect screening and retrospective data analysis (4) as well as human biomonitoring (in-vitro HLM/S9 fraction assays and in-vivo human metabolism). This represents the first chemical exposure analysis to some key chemicals such as bisphenol A using WBE.

(iii) Demonstrating that WBE, including enantiomeric profiling of water utilising mass spectrometry and chiral separations in the context of illicit drug speciation, can provide information on abuse trends (3, 5). This represents the first report using enantiomeric profiling of chiral drugs of abuse in WBE, which can provide information on abuse trends and potency of chiral drugs used. This research fed directly into WBE methodology Europe-wide through SCORE (6), the first Europe-wide study of illicit drug use through sewage biomarker analysis using WBE. The Bath-developed analytical research methods were applied alongside other methods developed by the SCORE group, to compare illicit drug use across 19 European Countries (6).

This research has been conducted in a strong cross-sectoral and transdisciplinary collaborative ethos within the projects EU SEWPROF (2012-16), EU SCORE, international GCRF projects ReNEW (2017-20), EDGE (2020-21) and EWS-C19 (2020-21), as well as through Leverhulme, UK Research Council funding and national UKRI N-WESP (2020-21).

3. References to the research

1. Petrie, B, Youdan, J, Barden, R & Kasprzyk-Hordern, B 2016, 'Multi-residue analysis of 90 emerging contaminants in liquid and solid environmental matrices by ultra-high-performance liquid chromatography tandem mass spectrometry', *Journal of Chromatography A*, vol. 1431, pp. 64-78. https://doi.org/10.1016/j.chroma.2015.12.036

2. Proctor, K, Petrie, B, Lopardo, L, Muñoz, DC, Rice, J, Barden, R, Arnot, T & Kasprzyk-Hordern, B 2021, 'Micropollutant fluxes in urban environment – A catchment perspective', *Journal of Hazardous Materials*, vol. 401, 123745. https://doi.org/10.1016/j.jhazmat.2020.123745

3. Lopardo, L, Cummins, A, Rydevik, A & Kasprzyk-Hordern, B 2017, 'New Analytical Framework for Verification of Biomarkers of Exposure to Chemicals Combining Human Biomonitoring and Water Fingerprinting', *Analytical Chemistry*, vol. 89, no. 13, pp. 7232-7239. https://doi.org/10.1021/acs.analchem.7b01527

4. Lopardo, L, Petrie, B, Proctor, K, Youdan, J, Barden, R & Kasprzyk-Hordern, B 2019, 'Estimation of community-wide exposure to bisphenol A via water fingerprinting', *Environment International*, vol. 125, pp. 1-8. https://doi.org/10.1016/j.envint.2018.12.048

5. Kasprzyk-Hordern, B & Baker, DR 2012, 'Estimation of community-wide drugs use via stereoselective profiling of sewage', *Science of the Total Environment*, vol. 423, pp. 142-150. https://doi.org/10.1016/j.scitotenv.2012.02.019

6. Thomas, KV, Bijlsma, L, Castiglioni, S, Covaci, A, Emke, E, Grabic, R, Hernández, F, Karolak, S, Kasprzyk-Hordern, B, Lindberg, RH, Lopez de Alda, M, Meierjohann, A, Ort, C, Pico, Y, Quintana, JB, Reid, M, Rieckermann, J, Terzic, S, van Nuijs, ALN & de Voogt, P 2012, 'Comparing illicit drug use in 19 European cities through sewage analysis', *Science of the Total Environment*, vol. 432, pp. 432-439. https://doi.org/10.1016/j.scitotenv.2012.06.069

4. Details of the impact

Development, adaptation and implementation of a new diagnostic technology (water fingerprinting by WBE) for estimation of illicit drug usage at a community level across Europe.

Wastewater-based epidemiology (WBE) offers an evidence-based public health risk prediction system that can help prevent disease and promote environmental health across the globe. The EU funded SCORE group and SEWPROF project developed a wastewater-based epidemiology tool using urban water-fingerprinting, including University of Bath developed research methods for enantiomeric profiling, data analysis and sampling approaches (**5, 6**). This WBE tool was adopted and implemented by the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) in 2016. The EMCDDA provides the EU and its Member States with a factual overview of European drug problems and a solid evidence base to support the drugs debate and offers policymakers the data to inform drug laws and strategies. It also supports professionals and practitioners working in the field. Since 2016, SCORE's WBE data has fed directly into the Europe-wide evidence based early warning system: *"Wastewater analysis has now demonstrated its potential as a complement to established monitoring tools and has moved from being an experimental technique to being a new method in the epidemiological toolkit*" [A; EMCDDA European Drug Report 2016].

Since 2016, SCORE's WBE data has been included in the annual EMCDDA Drugs reports via addition of city-level information from European research networks, which complements national data in the areas of wastewater analysis and drug-related hospital emergencies and enriches understanding of both drug consumption patterns and harms across Europe [A, B]. The approach is acknowledged as a key game changer in this area:

"The problem of measuring drug use, a complex, hidden and often highly stigmatised behaviour, is a central component of the work carried out by the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA). (...) [SCORE research], based on the analysis of municipal wastewater for drugs and drug residues, provides us with the

opportunity to obtain more timely information on geographical and temporal drug use patterns (…) its ability to deliver near-real-time data is particularly relevant to the mercurial nature of today's drug problem (…) wastewater analysis can help health and treatment services in a number of ways" [C; Director of EMCDDA].

WBE is also being applied in a wider range of contexts. The concept of WBE is being implemented by DEFRA as an evidence-based tool for monitoring SARS-CoV-2 prevalence in coronavirus pandemics, feeding into the Joint Biosecurity Centre [D, E; group includes Bath], while Professor Kasprzyk-Hordern has also co-authored a US-CDC/Wellcome/UK Science & Innovation Network White Paper on Addressing Antimicrobial Resistance in the Environment [F]. This emphasises the broader applicability and transferability of the developed methodologies.

Development of policy and practice on environmental health with Wessex Water.

Since 2010, Professor Kasprzyk-Hordern's research on water fingerprinting and comprehensive spatiotemporal profiling of pollution in the Avon Catchment (**1, 2, 3, 4**) has led to significant impact on a key project partner and research collaborator, Wessex Water (WW), a major regional public water utility company serving a population of 2,800,000. This research has shaped the strategic direction of WW, shifting their focus to WBE to look at the wider impact on public health, environment and ecosystem, informed investment decisions and improved their ability to detect and analyse a wider range of compounds and their metabolites using new rapid analytical techniques.

Specifically, the Bath research has been an essential resource for the long term planning of technologies at sewage treatment works by WW, to respond to changing environmental standards and contaminants of emerging concern [G]. Importantly, the impact goes beyond the technical aspects, reaching into mitigating social inequality and enhancing regional collaborative working.

The Director of Environmental Strategy at Wessex Water states the direct benefits to WW from the collaborative research with the Bath group [G]; these include:

- *"Improved Wessex Water's ability to detect and analyse a wider range of compounds and their metabolites using new rapid analytical techniques; improved sampling methods and influenced sampling sites;*
- *Informed Wessex Water priorities including investment decisions and future areas of work, i.e. Social Prescribing and reducing medicines waste (GBP1,000,000 investment), UKWIR AMR [Anitmicrobial resistance] programme (the choice of site and methods); NERC FRESH project (incorporating methods for evaluating new technologies). These research areas have been incorporated into our PR19 Business Plan (2020 to 25) which was approved by Ofwat and the Secretary of State in December 2019;*
- *Contributed to Wessex Water shift in focus from characterising wastewater to looking at the wider impact on the environment, ecosystem and public health;*
- *Enhanced local / regional collaborative working […] the social prescribing work can contribute towards the green recovery and address social inequality which has been revealed through the Covid-19 crisis;*
- *Raised awareness and understanding of the wider impact of contaminants in our sewage and receiving watercourses"* [G].

5. Sources to corroborate the impact

[A] European Drug Reports 2016 - 2020, published by EMCDDA.
https://www.emcdda.europa.eu/publications-database?search_api_views_fulltext=european+drug+report

[B] EMCDDA Wastewater-based epidemiology and drugs topic page.
http://www.emcdda.europa.eu/wastewater-analysis

[C] European Monitoring Centre for Drugs and Drug Addition (2016) 'Assessing illicit drugs in wastewater, Advanced in wastewater based epidemiology', Insights 22, Publications Office of the European Union, Luxemburg; PDF file from:
http://www.emcdda.europa.eu/publications/insights/assessing-drugs-in-wastewater_en

[D] DEFRA Announcement, "Group to measure for coronavirus prevalence in waste water", June 2020.
https://www.gov.uk/government/news/group-to-measure-for-coronavirus-prevalence-in-waste-water

[E] UK Government Press Release, "Sewage signals early warning of coronavirus outbreaks", October 2020.
https://www.gov.uk/government/news/sewage-signals-early-warning-of-coronavirus-outbreaks

[F] Initiatives for Addressing Antimicrobial Resistance in the Environment; US-CDCX/Wellcome/UK Science & Innovation Network White Paper.
https://wellcome.org/sites/default/files/antimicrobial-resistance-environment-report.pdf
(pp. 31-45)

[G] Wessex Water: letter from Director of Environmental Strategy, 7 September 2020.