PHARMACEUTICALS AND PERSONAL CARE PRODUCTS IN THE ENVIRONMENT IN CHINA

Xiaowen Wang

Doctor of Philosophy

University of York

Environment

September 2015

ABSTRACT

The introduction of bioactive chemicals from pharmaceuticals and active ingredients in personal care products (hereafter 'PPCPs') may pose a threat to ecosystems and human health. With advances in monitoring and detection, Chinese scientists have established PPCPs as pervasive pollutants in water bodies. While the full effects of PPCPs are not yet fully understood, concern is growing about the implications of PPCPs in the environment. This research employed a combination of environmental, social, and economic data to better understand the ecological risks and policy options, as well as the general publics' behavior, preferences and willingness to pay for measures aimed at preventing pollution by PPCPs in China. To achieve these aims, I conducted a structured review of the published scientific literature, took a series of qualitative interviews with Chinese scientists' working in this field and finally collected original survey data from residents living in China.

The first section of my thesis is based on the results from the structured review of the published scientific literature relating to PPCP pollution in China. This chapter provides the basis for understanding perceptions of risk among scientists and the public, and highlight what further research is needed. The second section describes the results from a series of semi-structured interviews with Chinese scientists and explores in depth their perspectives, opinions, and attitudes on current PPCP research and on future needs in the field. The third section is based on the analysis of results from a custom designed survey of Chinese residents. Results highlight that disposal of unwanted PPCPs in the trash is by far the most common disposal method and identifies significant heterogeneity in attitudes towards a proposed hypothetical disposal program. Finally the results from the contingent valuation experiment suggest a substantial willingness to pay for policy measures aimed at reducing PPCP pollution.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Many thanks to my supervisors Dr. Murray Rudd (Emory University, USA), Dr. Peter Howley and Professor Alistair Boxall (University of York, UK) for providing help and support throughout my PhD.

For my time in Xiamen, China, I would like to thank Professor Shenghui Cui and Professor Yongguan Zhu for the help they provided during my survey research.

For my PhD viva, I would like to express my sincere thanks to my internal examiner Dr Samarthia Thankappan (University of York, UK), and external examiner Dr Mirko Moro (University of Stirling, UK), their valuable comments have greatly improved my thesis.

AUTHOR'S DECLARATION

The papers that comprise CHAPTER 3 and CHAPTER 4 have multiple authors and have been published (see References below). For those two chapters, I collected the data and performed the analysis, and the other authors acted in a supervisory role. Therefore I declare that the work contained in this thesis is my own and has not been submitted for any other degree or award. All sources are acknowledged as References.

References

Wang, X., Howley, P., Boxall A., and Rudd, M. (2015). Behaviour, preferences and willingness to pay for measures aimed at preventing pollution by pharmaceuticals and personal care products in China. *Integrated Environmental Assessment and Management.* DOI: 10.1002/ieam.1746

Wang, X., Boxall A., Howley, P., and Rudd, M. (2015). Priority research questions on the environmental impacts of pharmaceutical and personal care products in China: insights from Chinese scientists. *Chinese Journal of Urban and Environmental Studies.* DOI: 10.1142/S2345748115500220

CHAPTER ONE

Introduction

Pharmaceuticals and personal products (PPCPs) in the environment

In recent years, environmental concerns and research on emerging pollutants (EPs, chemicals which are not normally monitored in the environment, while having the possibilities to enter into the environment and lead to potential adverse effects to both ecological systems and human health) have increased (Geissen et al. 2015). Pharmaceuticals and personal care products (PPCPs) are one of a number of types of emerging pollutants, which bioactive compounds and metabolites have been found in groundwater, surface water, drinking water and agricultural lands (Daughton and Ternes 1999; Zhou et al. 2013), and which have become an important focus (Boxall et al. 2012; Stuart et al. 2012; Richardson and Ternes 2014)

Categories of PPCPs in the environment

The range of PPCPs is large and diverse, including chemicals of pharmaceuticals, and active ingredients of daily personal care products (Daughton and Ternes 1999).

Pharmaceuticals

Pharmaceuticals are chemicals of products that are used to diagnose, treat or prevent illness of both human beings and animals, or chemicals of illicit drugs (Sirbu et al. 2006). Pharmaceuticals identified in environmental samples can be categorized into several representative classes according to their therapeutic functions, including antibiotics (human-used and veterinary), non-steroidal anti-inflammatory drugs (NSAID), blood lipid regulators, antiepileptics, hormones, beta-blockers (antihypertensives), antidepressants, antineoplastics, X-ray contrast media, and β_2-sympathomimetics (bronchodilator) (Daughton and Ternes 1999; Sirbu et al. 2006; Santos et al. 2010). Table 1.1 shows the examples, and potential effects or risks of each class of pharmaceuticals.

Table 1. 1 - PPCPs identified in environmental samples, adapted from (Daughton and Ternes 1999; Sirbu et al. 2006)

Classes	Examples	Suitable detection technologies	Examples of potential effects or risks
Pharmaceuticals			
Antibiotics	Sulfonamides Fluoroquinolones	LC-MS or LC-MS/MS	Antibiotic resistance (Daughton and Ternes 1999); Persistence in the environment (Santos et al. 2010)
NSAID	Acetaminophen Diclofenac Ibuprofen Ketoprofen Naproxen	LC-MS or LC-MS/MS	Chronic toxicity to non-targeted organism under prolonged exposure (Santos et al. 2010)
Blood lipid regulators	Clofibrate Gemfibrozil	LC-MS or LC-MS/MS	Threat to non-targeted organism (Santos et al. 2010)
Antiepileptics	Carbamazepine	LC-MS or LC-MS/MS	Persistence in the environment (Santos et al. 2010)
Hormones	Estradiol 17-Ethinyl Estradiol	LC-MS or LC-MS/MS	Bioaccumulation within aquatic organisms (Santos et al. 2010)
Beta-blockers (antihypertensives)	Bisoprolol Metoprolol	LC-MS or LC-MS/MS	A possible environmental risk under prolonged exposure (Santos et al. 2010)
Antidepressants	Diazepam	LC-MS or LC-MS/MS	A decrease in reproduction for targeted organism (Santos et al. 2010)
Antineoplastics	Cyclophosphamide Ifosfamide	LC-MS or LC-MS/MS	More data needed to assess chronic risks (Santos et al. 2010)
X-ray contrast media	Diatrizoate	LC-MS or LC-MS/MS	More data needed to assess chronic risks (Santos et al. 2010)
β_2-sympathomimetics (bronchodilator)	Albuterol	LC-MS or LC-MS/MS	N/A
Personal care products			
Antiseptics	Triclosan	GC-MS or GC-MS/MS	Bacteria resistance (Daughton and Ternes 1999)
Musks (synthetic)	Nitro And polycyclic musks	GC-MS or GC-MS/MS	Bioaccumulation within fish (Daughton and Ternes 1999)
Sun screens agents	Methybenzylidene Camphor Avobenzene	GC-MS or GC-MS/MS	Bioaccumulation within fish (Daughton and Ternes 1999)

Personal care products

Personal care products are active ingredients of products that are used directly by the consumers and are mainly used as cosmetics, toiletries, and fragrances (Sirbu et al. 2006), such as bath additives, shampoos, hair tonic, skin care products, hair sprays, setting lotions, hair dyes, oral hygiene products, soaps, sun screens, perfumes, aftershaves, etc. (Daughton and Ternes 1999). Personal care products identified in environmental samples can be mainly categorized into three classes due to their functions, which are antiseptics, musks (synthetic), and sun screens agents (Daughton and Ternes 1999; Sirbu et al. 2006). Table 1.1 presents the example generic names, and potential effects or risks of each class of personal care products.

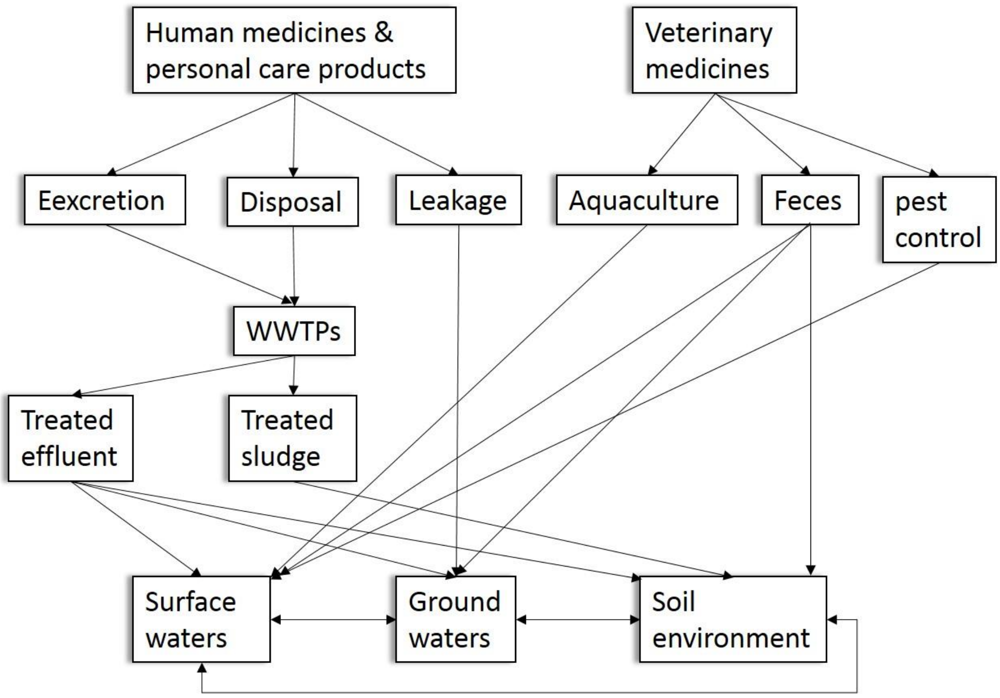

Figure 1. 1 The routes of PPCPs introduced into the environment

Routes of PPCPs in the environment

The major and most important sources of PPCPs in the environment are the effluent of wastewater treatment plants (WWTPs) which origins are mainly from the use and disposal of human-use pharmaceuticals and personal care products; and surface run-off which origins are mainly from the use of veterinary medicines for agriculture and aquaculture (Daughton and Ternes 1999). Figure 1.1 illustrates the routes of PPCPs introduced in the environment.

Routes of human-use pharmaceuticals and personal care products in the environment

Compounds of human-use pharmaceuticals and active ingredients of personal care products can be introduced into the environment primarily from the following ways (Daughton 2006; Sirbu et al. 2006; Gibson 2010) (see Figure 1.1):

(1) Metabolic excretion, vomitus, sweat, showering and washing of individuals after using PPCPs;
(2) Disposal of unwanted or expired PPCPs to sewage system by individuals;
(3) Disposal of unwanted or expired PPCPs s to landfill by individuals;
(4) Disposal of treated/untreated hospital wastes and PPCPs manufactories' wastes to sewage systems;
(5) Leakage from sewage systems;

After the treatment procedures of WWTPs, the treated effluent and sludge that contain the residual chemicals of PPCPs and their metabolites from (1), (2) and (4) will be released to surface waters by discharging into the receiving rivers, ground waters by recharging into aquifers, and soil environment by recycling or reusing for irrigation and other agricultural purpose (Richardson et al. 2005; Daughton 2006; Li 2014). Compounds of PPCPs containing in (3) and (5) can enter into the groundwater through underground leakage (Boxall et al. 2003; Eggen et al. 2010; Peng et al. 2014).

Routes of veterinary medicines in the environment

Chemicals of veterinary medicines can be introduced into the environment mainly from the purpose of agriculture, such as (Halling-Sorensen et al. 1998; Daughton 2006; Sirbu et al. 2006; Gibson 2010) (see Figure 1.1):

(1) Aquaculture (such as feed drugs and resulting metabolic excreta);
(2) Feces and other metabolic excreta from domestic animals taken therapeutic

treatment;

(3) Feces and other metabolic excreta from poultry and livestock taken growth promoters for production purpose;
(4) Medicines used as pest control agents on farmland and orchard;
(5) Medicines spray for treatment on farmland and orchard;

The use of medicines on aquaculture can directly release their chemicals to the surface waters. Chemicals of veterinary medicines containing in (2) and (3) can be discharged to the soil environment as fertilizers on the farmland, surface waters by storm water overflow, and ground waters by leakage. Compounds of (4) and (5) can be released to the surface waters through storm water overflow (Boxall et al. 2003; Daughton 2006; Eggen et al. 2010; Peng et al. 2014).

Detection of PPCPs in the environment

To detect the occurrence of PPCPs in the environment, analytical methods have been developed by scientists to provide the information of concentrations of different kinds of PPCPs in various environmental matrices (such as water, solids) (Kolpin et al. 2002; Brooks et al. 2012). The main analytical tools used to detect the occurrence and to measure the concentrations of PPCPs from prepared samples are gas chromatography-mass spectrometry (GC-MS) or GC with tandem MS (GC-MS/MS), and liquid chromatography-mass spectrometry (LC-MS) or LC with tandem MS (LC-MS/MS) (Fatta et al. 2007; Brooks et al. 2012). By combining the features of gas chromatography with mass spectrometry, GC-MS or GC-MS/MS can be used to detect various materials within a prepared sample, especially personal care products which are weakly polar, volatile, and hydrophobic. By combining the features of liquid chromatography (LC) with the mass spectrometry (MS), LC-MS or LC-MS/MS can be used for analysis of pharmaceuticals that are relatively strong polar, non-volatile, and hydrophilic than personal care products (Brooks et al. 2012). Table 1.1 shows the suitable detection technologies for each class of PPCPs identified in the environment.

With the advanced analytical technologies, chemical compounds of PPCPs and their metabolites have been detected worldwide in various environmental matrices (Halling-Sorensen et al. 1998; Daughton and Ternes 1999; Heberer 2002; Eggen et al. 2010; Zhou et al. 2013; Kosma et al. 2014), and scientists have established PPCPs as pervasive pollutants in water bodies (Sacher et al. 2001; Kolpin et al. 2002; Ternes et al. 2004; Weigel et al. 2004; Roberts and Thomas 2006) that could pose threats to both ecosystem and human health (Daughton and Ternes 1999; Bound and Voulvoulis 2005; Santos et al. 2010; Rosi-Marshall and Royer 2012; Ferguson et al. 2013).

Regulation of PPCPs in the environment

Due to the widespread detection of chemicals of PPCPs in the environment, an increasing number of countries have concerned about the adverse effects of PPCPs in the environment to human and ecosystem health, and have implemented or planned relevant regulations or interventions to prevent the release of PPCPs into the environment. Those regulation or interventions can be divided into social and scientific ways. Social way means that the regulations and interventions on reducing PPCPs into the environment did not need direct scientific experiments or techniques, such as pharmaceutical take back program; and scientific way means that the regulations and interventions needed to include the scientific instruments. Table 1.2 shows regulations and interventions have been implemented or planned on controlling PPCPs enter into the environment from the social way.

Table 1. 2 Regulations on reducing PPCPs in the environment (Stoddard and Huggett 2012)

Countries	Year	Scope	Institution	Regulation and Intervention
USA	2010	National	US Drug Enforcement Administration (DEA)	*National Take Back Initiative* : to help residents dispose of unwanted medicines safely; twice; 309 tons medicine collected
USA	2013	National	Congress [https://www.congress.gov/bill/113th-congress/house-bill/1385]	*H.R.1385 - Safe Cosmetics and Personal Care Products Act of 2013*: "Requires any brand owner engaged in bringing a cosmetic to market for use in the United States to register annually and pay a fee for oversight and enforcement of this Act"… [introduced in House]

For scientific way, regulations on environmental risk assessment for pharmaceuticals (PERA) have been taken in various countries, which means pharmaceutical products listed by relevant policy acts have to pass the designed PERA to get an appraisal to prove they have no risk to the environment (Straub and Hutchinson 2012). The basic procedure of environmental risk assessment of specific chemical is to calculate their risk quotient (RQ, which value measures the risks of those chemicals to organisms in the aquatic environment (Kosma et al. 2014)) or their hazard quotient (HQ, which value measures the risks of those chemicals to organisms in the terrestrial environment (Prosser and Sibley 2015)). The value of RQ (or HQ) of a certain chemical is equal to the ratio between its measured environmental concentration (MEC) and predicted no effect concentration (PNEC) (see equation (1.1)).

$$\mathrm{RQ\ (or\ HQ)} = \mathrm{MEC/PNEC} \tag{1.1}$$

Here, MEC is the predicted or measured maximum daily concentration of the specific compound in some environment. PNEC is the limit concentration of the specific compound bringing no risks to targeted organisms (like algae) according to existing experimental data. For a certain PPCP, when the value of $\mathrm{RQ\ (or\ HQ)} > 1$, its daily use concentration in the sample has exceeded its no adverse effects concentration, which indicates it have high potential risks to the environment; when the value of RQ (or HQ) locates in $[0.1, 1]$, which indicates medium potential risks to the environment; and when the value of $\mathrm{RQ\ (or\ HQ)} < 0.1$, its potential risk to the environment is considered as low (Hernando et al. 2006; Kosma et al. 2014). Table 1.3 shows the countries that have implemented or planned PERA regulations.

Table 1. 3 PERA regulations in various countries, adapted and derived from Straub and Hutchinson (2012)

Countries	Institution or Act	Requirements of the regulation or intervention
USA	US Center for Drug Evaluation and Research (CDER) within US Food and Drug Administration	"all applications or petitions requesting Agency action must be accompanied by either an EA or a claim of categorical exclusion; failure to submit one or the other is sufficient grounds for refusing to file or approve the application"
European Union	EU Directive 93/39/EEC	"to give indications of any potential risks presented by the medicinal product to the environment"
Canada	New Substances Notification Regulation (Chemicals and Polymers)	Authorities must be reported to if new introduced chemical products are not on the Canadian Domestic Substances List [a PERA is developing]
Japan	NA	[a PERA is developing]
Australia	NA	[a PERA is requiring]

Research Purpose

China produces more than 20% of the whole amount of the world's pharmaceutical production, and occupies nearly 10% of the global personal care products consumption markets (Liu and Wong 2013). The chemical components of PPCPs have already been found in different environmental media throughout China (Liu and Wong 2013). The number of scientific studies in this area has increased since 2006, with investigations of issues like the occurrence, fate, effects, and removal efficiencies of PPCPs in the environment in China (Sui et al. 2010; Peng et al. 2012; Liu and Wong 2013; Zhou et al. 2013; Sun et al. 2014; Wang et al. 2014).

Scientific research provides useful data on, and technology for, understanding PPCPs (e.g., concentrations and adverse effects of specific PPCPs under certain conditions), and methods to detect and reduce residues of PPCPs in the WWTPs and natural environment. However, to take actions on managing and controlling PPCPs in the environment, there is a pressing need to involve the government, who will need more information on both technological and social aspects of PPCP use and disposal to design policy and formulate evidence-based regulation. The purpose of my research was to understand the ecological risks and policy options, as well as the general publics' preferences and attitudes for measures aimed at preventing pollutions by pharmaceuticals and personal care products (PPCPs) in China. To fulfill this, I took a two-fold approach: I examined the insights of scientific experts working on PPCPs at the household level; and second, I calculated public preferences and willingness to pay on using and reducing PPCPs, a novel application of economic valuation of contaminants in the environment. This research aims to provide a broader picture of both scientists' and citizens' beliefs and behaviors' for policy-makers. To the best of our knowledge, at present no social science methods have been taken on studying issues related to PPCPs in the environment in China.

My research questions are developed and explained in three chapters, each providing a different perspective on one part of the challenge to controlling PPCPs in the environment. The chapters review technical issues, outline current Chinese scientists' thinking about the state of research and policy in China, and calculate citizens' willingness to pay to prevent PPCPs from entering the environment in a major Chinese city.

Objectives for Each Chapter

The exact risks of PPCPs are not yet fully understood (Fent et al. 2006; Girardi et al. 2011; Narvaez and Jimenez C 2012) and the links between PPCPs in the environment and the final ecosystem services that matter to human health are also not well defined (Huerta et al. 2013). Concern is growing about the implications of PPCPs in the environment (Narvaez and Jimenez 2012) and the topic has been identified as an important international research priority (Boxall et al. 2012; Rudd et al. 2014). The existing literature review of potential risks of PPCPs in the environment in China (e.g. Bu et al. (2013)) mainly focused on the concentration. As more and more environmental risk assessment of PPCPs have been conducted, I was interested to identify the risk status and levels of specific PPCPs in different parts of China by investigating the results of current scientific studies. Based on the investigation, I aimed to provide and discuss the possible regulation options on preventing or reducing PPCPs in the environment and their feasibilities.

Chapter Two first reviewed the published scientific literature that studied and calculated the potential risks of PPCPs in the terrestrial and aquatic environments in China, which provided the basis for understanding perceptions of risk among scientists and the public. According to this review, I found that some categories of PPCPs have resulted in high potential risks to the environment in both aquatic and terrestrial environment of China under international standards. Human activities did pose an important influence on the levels of potential risks of PPCPs in the environment, especially through the WWTPs discharging and livestock feeding. Chinese government should beware of the current status of PPCPs and take precautions by making proper policy decisions. Following the risks status summarized by the review, I provided and discussed four regulation options on managing PPCPs in the environment.

The third chapter reports the results of semi-structured interviews with Chinese experts researching PPCPs in the environment. To help identify the most pressing global knowledge gaps arising from the risks of PPCPs in the environment, Rudd et al. (2014) surveyed 535 environmental scientists from 57 different countries who were conducting PPCP-relevant research. The scientists ranked 22 important PPCP research priorities (first identified by Boxall et al., 2012) and provided 171 additional PPCP research questions that they thought were also important. Rudd et al. (2014) prepared Chinese and English versions of their survey and, based on the Chinese responses, found that the research orientation of the Chinese scientists mostly focused on "issues of managing risk profiles, effluent treatment, residue bioavailability and regional assessment" (p.576). I was interested in the reasons behind the prioritization of the Chinese scientists and wanted to explore in more depth the issues that scientists deemed as important given the Chinese context of widespread water pollution and rapid growth in industrial production, and rapidly increasing household consumption of PPCPs.

In this exploratory work on scientists' perceived research and management needs for PPCPs in the Chinese environment, I conducted semi-structured, qualitative interviews with Chinese experts conducting PPCP-related research. In telephone interviews, I used the eight research questions that Chinese scientists had earlier ranked as relatively important (compared to western scientists) as guiding questions that provided the opportunity to probe Chinese scientists' perspectives, opinions, and attitudes on current PPCP research and on future needs in the field. That could help to build the scientific understanding of the current PPCP research landscape in China and garner in-depth suggestions on how to prioritize and communicate environmental science, making it more salient for policy decisions on dealing with PPCPs risks in China.

The fourth chapter examined Chinese citizens' preferences, attitudes, and behavior regarding the disposal of unused PPCPs as well as their willingness to pay for measures aimed at reducing the impact of PPCP pollution in Xiamen, a large coastal city (population = 3.5 million) in southern China.

Our survey asked respondents from 800 households about their general awareness of PPCP contamination and disposal practices, and their willingness to participate in a hypothetical voluntary disposal program established at a local pharmacy for safe disposal of PPCPs. We also used a contingent valuation scenario in the survey to estimate how much the general public would be willing to pay for measures aimed at preventing PPCP contamination in Xiamen. To date only Kotchen et al. (2009), who examined Californian residents' willingness to pay for a disposal program implemented at a local pharmacy, has assessed the economic benefits of controlling PPCP release into the environment. Our results should be of interest to policymakers looking for ways to mitigate the introduction of PPCPs in the environment and for researchers in other developing countries who are seeking to conduct increasingly detailed cost-benefit or cost-effectiveness analyses of environmental management issues that involve contaminants in the environment.

The final chapter summarizes the results and conclusions of the main three chapters to provide suggestions on management, policy decision-making and future work on regulating pharmaceuticals and personal care products (PPCPs) in the environment in China.

References

Bound, J.P. and Voulvoulis, N. (2005). Household disposal of pharmaceuticals as a pathway for aquatic contamination in the United Kingdom. *Environmental Health Perspectives* 113(12): 1705-1711.

Boxall, A., Rudd, M.A., Brooks, B.W., et al. (2012). Pharmaceuticals and personal care products in the environment: what are the big questions? *Environmental Health Perspectives* 120(9): 1221-1229.

Boxall, A.B., Kolpin, D.W., Halling-Sørensen, B. and Tolls, J. (2003). Peer reviewed: are veterinary medicines causing environmental risks? *Environmental science & technology* 37(15): 286A-294A.

Brooks, B.W., Berninger, J.P., Ramirez, A.J. and Huggett, D.B. (2012). Perspectives on Human Pharmaceuticals in the Environment. *Human Pharmaceuticals in the Environment: Current and Future Perspectives*. Brooks, W.B. and B.D. Huggett. New York, NY, Springer New York**:** 1-16.

Bu, Q., Wang, B., Huang, J., Deng, S. and Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. *J Hazard Mater* 262: 189-211.

Daughton, C.G. (2006). Origins and fate of PPCPs in the environment. *U.S. Environmental Proection Agency (USEPA)* 1 p.

Daughton, C.G. and Ternes, T.A. (1999). Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives* 107: 907-938.

Eggen, T., Moeder, M. and Arukwe, A. (2010). Municipal landfill leachates: a significant source for new and emerging pollutants. *Science of the Total Environment* 408(21): 5147-5157.

Fatta, D., Achilleos, A., Nikolaou, A. and Meriç, S. (2007). Analytical methods for tracing pharmaceutical residues in water and wastewater. *TrAC Trends in Analytical Chemistry* 26(6): 515-533.

Fent, K., Weston, A.A. and Caminada, D. (2006). Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology* 76(2): 122-159.

Ferguson, P.J., Bernot, M.J., Doll, J.C. and Lauer, T.E. (2013). Detection of pharmaceuticals and personal care products (PPCPs) in near-shore habitats of southern Lake Michigan. *Science of the Total Environment* 458: 187-196.

Geissen, V., Mol, H., Klumpp, E., et al. (2015). Emerging pollutants in the environment: A challenge for water resource management. *International Soil and Water Conservation Research* 3(1): 57-65.

Gibson, K. (2010). Pharmaceuticals and personal care products (PPCPs): Disposal, scientific, and regulatory challenges. *Environmental Quality Management* 20(1): 39-48.

Girardi, C., Greve, J., Lamshoeft, M., et al. (2011). Biodegradation of ciprofloxacin in water and soil and its effects on the microbial communities. *Journal of Hazardous Materials* 198: 22-30.

Halling-Sorensen, B., Nielsen, S.N., Lanzky, P.F., et al. (1998). Occurrence, fate and effects of pharmaceutical substances in the environment - A review. *Chemosphere* 36(2): 357-394.

Heberer, T. (2002). Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. *Toxicology Letters* 131(1-2): 5-17.

Hernando, M.D., Mezcua, M., Fernández-Alba, A.R. and Barceló, D. (2006). Environmental risk assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments. *Talanta* 69(2): 334-342.

Kolpin, D.W., Furlong, E.T., Meyer, M.T., et al. (2002). Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: A national reconnaissance. *Environmental Science & Technology* 36(6): 1202-1211.

Kosma, C.I., Lambropoulou, D.A. and Albanis, T.A. (2014). Investigation of PPCPs in wastewater treatment plants in Greece: occurrence, removal and environmental risk assessment. *Science of the Total Environment* 466: 421-438.

Li, W.C. (2014). Occurrence, sources, and fate of pharmaceuticals in aquatic environment and soil. *Environmental Pollution* 187: 193-201.

Liu, J.-L. and Wong, M.-H. (2013). Pharmaceuticals and personal care products (PPCPs): A review on environmental contamination in China. *Environment International* 59: 208-224.

Narvaez, J.F.V. and Jimenez C, C. (2012). PHARMACEUTICAL PRODUCTS IN THE ENVIRONMENT: SOURCES, EFFECTS AND RISKS. *Vitae-Revista De La Facultad De Quimica Farmaceutica* 19(1): 93-108.

Peng, X., Huang, Q., Zhang, K., et al. (2012). Distribution, behavior and fate of azole antifungals during mechanical, biological, and chemical treatments in sewage treatment plants in China. *Science of the Total Environment* 426: 311-317.

Peng, X., Ou, W., Wang, C., et al. (2014). Occurrence and ecological potential of pharmaceuticals and personal care products in groundwater and reservoirs in the vicinity of municipal landfills in China. *Science of The Total Environment* 490: 889-898.

Prosser, R. and Sibley, P. (2015). Human health risk assessment of pharmaceuticals and personal care products in plant tissue due to biosolids and manure amendments, and wastewater irrigation. *Environment international* 75: 223-233.

Richardson, B.J., Lam, P.K.S. and Martin, M. (2005). Emerging chemicals of concern: Pharmaceuticals and personal care products (PPCPs) in Asia, with particular reference to Southern China. *Marine Pollution Bulletin* 50(9): 913-920.

Richardson, S.D. and Ternes, T.A. (2014). Water Analysis: Emerging Contaminants and Current Issues. *Analytical Chemistry* 86(6): 2813-2848.

Roberts, P.H. and Thomas, K.V. (2006). The occurrence of selected pharmaceuticals in wastewater effluent and surface waters of the lower Tyne catchment. *Science of the Total Environment* 356(1-3): 143-153.

Rosi-Marshall, E.J. and Royer, T.V. (2012). Pharmaceutical Compounds and Ecosystem Function: An Emerging Research Challenge for Aquatic Ecologists. *Ecosystems* 15(6): 867-880.

Rudd, M., Ankley, G., Boxall, A. and Brooks, B. (2014). International scientists' priorities for research on pharmaceutical and personal care products in the environment. *Integrated environmental assessment and management* 10(4): 576-587.

Sacher, F., Lange, F.T., Brauch, H.-J. and Blankenhorn, I. (2001). Pharmaceuticals in groundwaters: analytical methods and results of a monitoring program in Baden-Württemberg, Germany. *Journal of Chromatography A* 938(1): 199-210.

Santos, L.H.M.L.M., Araujo, A.N., Fachini, A., et al. (2010). Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. *Journal of Hazardous Materials* 175(1-3): 45-95.

Sirbu, D., Curseu, D., Popa, M., Achimas-Cadariu, A. and Moldovan, Z. (2006). Environmental risks of pharmaceuticals and personal care products in water. *Tenth International Water Technology Conference, Alexandria, Egypt*.

Stoddard, K.I. and Huggett, D.B. (2012). Pharmaceutical Take Back Programs.

Straub, J.O. and Hutchinson, T.H. (2012). Environmental Risk Assessment for Human Pharmaceuticals: The Current State of International Regulations.

Stuart, M., Lapworth, D., Crane, E. and Hart, A. (2012). Review of risk from potential emerging contaminants in UK groundwater. *Science of The Total Environment* 416: 1-21.

Sui, Q., Huang, J., Deng, S., Yu, G. and Fan, Q. (2010). Occurrence and removal of pharmaceuticals, caffeine and DEET in wastewater treatment plants of Beijing, China.

Water Research 44(2): 417-426.

Sun, Q., Lv, M., Hu, A., Yang, X. and Yu, C.-P. (2014). Seasonal variation in the occurrence and removal of pharmaceuticals and personal care products in a wastewater treatment plant in Xiamen, China. *Journal of Hazardous Materials* 277: 69-75.

Ternes, T.A., Joss, A. and Siegrist, H. (2004). Scrutinizing pharmaceuticals and personal care products in wastewater treatment. *Environmental Science & Technology* 38(20): 392A-399A.

Wang, D., Sui, Q., Lu, S.-G., et al. (2014). Occurrence and removal of six pharmaceuticals and personal care products in a wastewater treatment plant employing anaerobic/anoxic/aerobic and UV processes in Shanghai, China. *Environmental Science and Pollution Research* 21(6): 4276-4285.

Weigel, S., Berger, U., Jensen, E., et al. (2004). Determination of selected pharmaceuticals and caffeine in sewage and seawater from Tromsø/Norway with emphasis on ibuprofen and its metabolites. *Chemosphere* 56(6): 583-592.

Zhou, L.-J., Ying, G.-G., Liu, S., et al. (2013). Occurrence and fate of eleven classes of antibiotics in two typical wastewater treatment plants in South China. *Science of the Total Environment* 452: 365-376.

CHAPTER TWO

Review of the ecological risk status of pharmaceuticals and personal care products (PPCPs) in the environment in China and discussion of policy options

Abstract

The introduction of bioactive chemicals from pharmaceuticals and active ingredients in personal care products (hereafter 'PPCPs') may pose a threat to ecosystems and human health. With advances in monitoring and detection, Chinese scientists have established PPCPs as pervasive pollutants in water bodies. While the full effects of PPCPs are not yet fully understood, concern is growing about the potential risks of PPCPs in the environment. This study reviewed the published scientific literature that took environmental risk assessment of PPCPs in China. Based on the results, this chapter presented the status and levels of potential risks of PPCPs in China, and discussed the feasibilities of three regulation options on reducing PPCPs.

Key words: Environmental risk assessment, potential risks of PPCPs, regulation options

Introduction

The scientific research on occurrence, fates and effects of pharmaceuticals and personal care products (PPCPs) in the environment has throughout the world grown over the past two decades (Halling-Sorensen et al. 1998; Daughton and Ternes 1999; Heberer 2002; Fent et al. 2006; Santos et al. 2010; Arpin-Pont et al. 2014; Rosi-Marshall et al. 2015). Even though, like other emerging contaminants, their accumulated risks to the environment and human beings are still uncertain, they have been already deemed as persistent pollutants in the environment and might pose chronic threats to both ecosystems and human health in the long run (Daughton and Ternes 1999; Petrie et al. 2015). For example, scientists have for some time been concerned about the risks of antibiotic resistance in aquatic organisms (Ashbolt et al. 2013; González-Pleiter et al. 2013).

To inform precautionary regulations and policies, environmental risk assessment methods have been developed and applied to PPCPs in the environment (de García et al. 2014). Currently, the most common methods of assessing the environmental risks of specific chemicals are to calculate their risk quotient (RQ, which value measures the risks of those chemicals to organisms in the aquatic environment (Kosma et al. 2014)) or their hazard quotient (HQ, which value measures the risks of those chemicals to organisms in the terrestrial environment (Prosser and Sibley 2015)). The value of RQ (or HQ) of a certain chemical is equal to the ratio between its measured environmental concentration (MEC) and predicted no effect concentration (PNEC) (see equation (2.1)).

$$\mathrm{RQ\ (or\ HQ)} = \mathrm{MEC/PNEC} \tag{2.1}$$

Here, MEC is the predicted or measured maximum daily concentration of the specific compound in some environment. PNEC is the limit concentration of the specific compound bringing no risks to targeted organisms (like algae) according to existing experimental data. For a certain PPCP, when the value of $\mathrm{RQ\ (or\ HQ)} > 1$, its daily use concentration in the sample has exceeded its no adverse effects concentration, which indicates it have high potential risks to the environment; when the value of $\mathrm{RQ\ (or\ HQ)}$ locates in $[0.1, 1]$, which indicates medium potential risks to the environment; and when the value of $\mathrm{RQ\ (or\ HQ)} < 0.1$, its potential risk to the environment is considered as low

(Hernando et al. 2006; Kosma et al. 2014).

Due to its large population, the rapid development of the economy, and an aging population, China is a key player in global PPCP production and use. China produces >20% of global pharmaceuticals and consumes nearly 10% of global personal care products (Liu and Wong 2013). The chemical components of PPCPs have already been found in different environmental media throughout China (Liu and Wong 2013). Figure 2.1 illustrates the citation frequencies of the most cited five PPCP-related papers in the world by Chinese scientists. The trend indicated the number of scientific studies in this area in China has increased since 2006, investigating issues like the occurrence, fate, effects, removal efficiencies and risk assessment of PPCPs in the water and soil environment (Sui et al. 2010; Tong et al. 2011; Peng et al. 2012; Liu and Wong 2013; Yan et al. 2013; Zhou et al. 2013; Li et al. 2014; Sun et al. 2014; Wang et al. 2014; Wu et al. 2014).

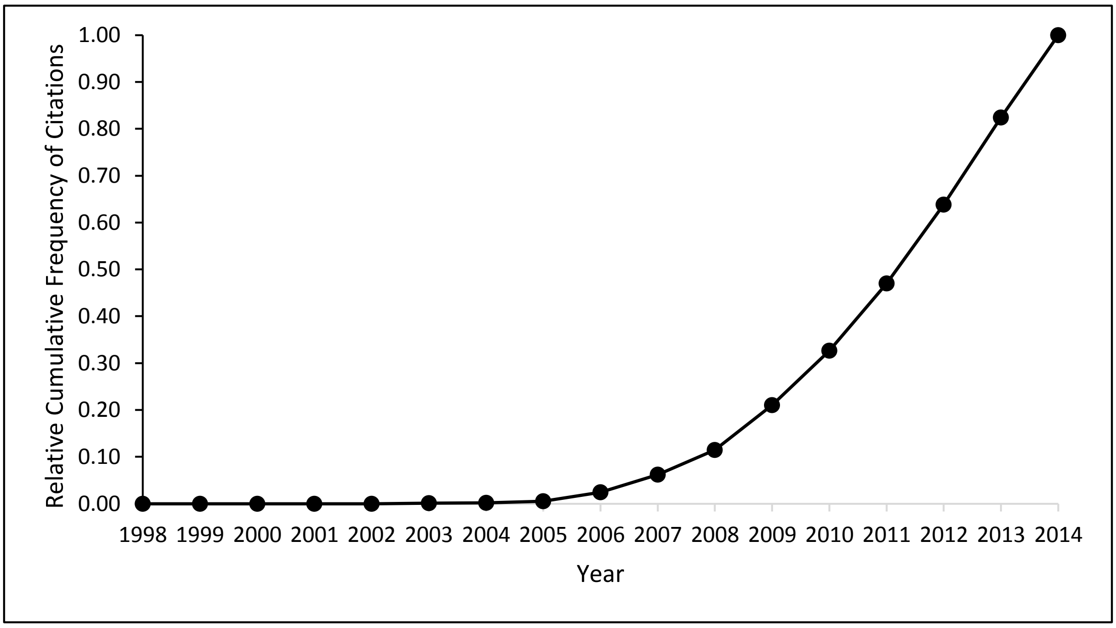

Figure 2. 1 The representative trend of peer-reviewed publications of studies related to PPCPs in the environment in China since 1998, which surrogated by the relative cumulative frequency of citations of the five most cited PPCP-related papers in the world (Halling-Sorensen et al. 1998; Ternes 1998; Daughton and Ternes 1999; Heberer 2002; Kolpin et al. 2002) by Chinese scientists. (Citation information were got from the ISI Web of Science database.)

Some reviews have been conducted on scientific research progress and status of PPCPs in the environment of China (Bu et al. 2013; Liu and Wong 2013; Wang et al. 2015; Zhang et al. 2015). Those existing PPCP-related reviews largely focused, however, on technical issues but did not discuss or compare the evidence-based policy options for PPCPs in China, especially the potential risks of PPCPs to ecosystems and human health. In addition to the scientific findings, management options for PPCPs should be proposed, discussed, and evaluated in order to help policy-makers make sound choices.

In order to help bridge science and policy, my aim was to conduct a risk- and policy-oriented review of PPCPs in the environment in China. In particular, I focused on the following three questions:

(1) What is the current status of risks of PPCPs in both soil and aquatic environment in China to both ecosystems and human health?
(2) Based on the current risk status and its future trajectory, are there any proper environmental policy options on regulating PPCPs in China?
(3) What information is needed to make informed decisions among them?

In this paper, first, I critically review the published articles (in Western and Chinese scientific journals) that have conducted environmental risk assessment or discussed ecological risks of PPCPs in the soil or water environment in China. Second, I provide and discuss policy options for managing PPCPs in China based on the current evidence.

Methods

Literature Search

To collect the scientific literature on environmental risk assessment or discussed specific ecological risks of PPCPs in China, the databases I examined were: ISI Web of Science (core collection); Science Direct; China National Knowledge Infrastructure (CNKI); and Wanfang Data. CNKI was initiated by Tsinghua University and Tsinghua Tongfang Company in 1996, and started to provide database service in 1999. Currently, it is "the largest aggregator and distributor of academic digital resources in China" (http://eng.scholar.cnki.net/about/intro.aspx); Wanfang Data was built in 1993, which is one of the largest and popular academic digital database in China. I drew on English language journal articles from ISI Web of Science (core collection) and Science Direct, and Chinese-language journal articles from CNKI and Wanfang Data (as the study scope was China, we restricted our review literature to articles written in either English or Chinese). From the trend of Figure 2.1, the scientific research on PPCPs in the environment in China began to increase in 2006; and the time we took this survey research was the end of 2014, so the temporal period for the literature search was chosen from 2006 to 2014. In order to focus on the most representative and defensible work on PPCPs in the environment in China, I only included peer-reviewed journal articles in the review.

Document Screening

The search protocol used to help identify the literature written in both English and Chinese that were widely related to risks or effects of PPCPs in the environment in China is illustrated in Table 2.1. This was a deliberately broad strategy to ensure that I captured as much of the relevant science as possible. I searched those articles by topic, which included title, abstract, and key words. When searching the two Chinese databases, I translated the English terms into Chinese and then used the translated words to identify literature written in Chinese.

Table 2. 1 – Key words used in literature search

Search constraints	Application of the search key words
Pharmaceuticals	Pharmaceutical* OR medicine* OR drug* OR hormone* OR antibiotic* OR "blood lipid regulator*" OR analgesic* OR anti-inflammatory OR beta-blocker* OR antidepressant* OR antiepileptic* OR antineoplastic* OR tranquilizer* OR retinoid* OR "diagnostic contrast media" OR "emerging contaminant*" OR "emerging pollutant*"
Personal care products	"Personal care product*" OR fragrance* OR musk* OR preservative* OR antiseptic* OR triclosan OR "sunscreen agent*" OR "UV filter*" OR nutraceutical*
Soil environment	Soil* OR sludge* OR biosolid* OR sediment* OR landfill*
Water environment	"Ground water*" OR "drinking water*" OR "surface water*" OR wastewater* OR sewage*
Ecosystems	Agricultur* OR farm* OR aquacultur* OR plant*
Human health	"Human health"
Risks	Contamination* OR pollution* OR ecotoxic* OR fish* OR invertebrate* OR algae OR earthworm*
Region	China

Data analysis

To help analyse the articles, I used NVivo software which is designed for the qualitative analysis of textual data, and could store text documents and help classify the articles in different themes by adding nodes.

Results

The initial search resulted in 2982 records (Table 2.2). After removing the duplicated documents, we refined the collected articles by title screening which aimed to remove non-relevant records by judging from the titles, and reduced the total number of articles to 452 records.

Table 2. 2 – Literature screening results

Databases	Search strategy	Initial results
ISI Web of Science	Data sources: core collection; Searched by: topic; Language: English and Chinese; Regions: China; Dates: 2006 to 2014	388 records
Science Direct	Data sources: journals articles; Searched by: title, abstract, and keywords; Dates: 2006 to 2014	248 records
CNKI	Data sources: journal articles; Searched by: topic; Language: Chinese; Dates: 2006 to 2014	707 records
Wanfang Data	Data sources: journal articles; Searched by: topic; Language: Chinese; Dates: 2006 to 2014	1639 records
Total number of articles in the initial screening		**2982 records**

The literature that was screened out of my study was typically about the engineering techniques to remove PPCPs, health issues (treatment of PPCP-related illness), non-PPCPs pollutants (e.g., heavy metal, pesticides, perfluorooctanesulfonic acid, polybrominated diphenyl ethers), nanoparticles, studies in regions outside of China, agricultural science and biology studies, review papers focused on foreign countries written by Chinese scientists, and adsorption and desorption of PPCPs in the environment. I then screened the remaining articles by reviewing their abstracts, and reduced the total number of articles to 147 records.

The literature removed at this stage mainly focused on: controlled laboratory experiments (samples not directly collected from the soil or water environment); and occurrence, fate, distribution, characteristics, identification, and removal of PPCPs (but which did not mention potential risks of PPCPs). After a review of the full texts of the remaining 147 articles, I finalized the literature selection with 60 useful articles that were in line with our screening criteria.

Risks of PPCPs in the environment in China

Studies identified and characteristics

Thirteen of the 60 articles (~21%) were written in Chinese. A total of 34 articles focused on antibiotics, and estrogens and other hormones in the environment were mentioned in 11 articles (18%). Only five articles (8%) discussed the risks of personal care products in the environment: three studied the effects of musks and two focused on triclosan. There were also six articles that studied a combination of PPCPs together.

Potential risks caused by PPCPs in effluent and receiving rivers of WWTPs

As an important source of PPCPs entering the environment, the status of wastewater treatment plants (WWTPS) have frequently been examined. Eleven articles discussed ecological risks or conducted environmental risk assessments of PPCPs in the effluents of WWTPs and/or their receiving waters. The targeted pharmaceuticals mainly included antibiotics (e.g., fluoroquinolone, sulfonamide, quinolone, and macrolide), analgesics, lipid regulators, anti-hypertensive, cholesterol lowering statin drugs, and anti-epileptics. The research was conducted in the south, north and west of China, which might indicate that the existence of above pharmaceuticals in the effluents of WWTPs are ubiquitous in China.

The highest concentration of pharmaceuticals in the effluents (at 1212 ng/L) was sulfamethoxazole (a kind of sulfonamide antibiotic) in Chongqing, a major city located in northwestern China. The RQ value showed that antibiotics (mainly were sulfadiazine, sulfamethoxazole, ofloxacin, azithromycin, and erythromycin) in effluent posed a high risk to algae, while the potential risks in their receiving river was medium (Yan et al. 2014). With low RQ values (all less than 0.1) in both WWTP effluent and receiving water, a study taken in Hangzhou (an important city located in the south of China) showed no risks to the aquatic environment from fluoroquinolone antibiotics (Tong et al. 2011).

About 200 kilometers away, research undertaken in Shanghai (a highly developed city in China) showed that diclofenac (a kind of analgesic) in the receiving water of WWTPs posed a high risk to aquatic organisms as the RQ value was above 1.5 (Duan et al. 2013). In some effluents and receiving waters of WWTPs of Beijing (the capital city of China), the RQ values of mefenamic acid (a NSAID), trimethoprim (an antibiotic), and gemfibrozil (a lipid regulator) indicated their medium risks. DEET (an insect repellent) posed no risk to the aquatic environment based on its low RQ value (Dai et al. 2014).

Potential risks caused by PPCPs in surface water and sediments

Twenty-eight articles discussed the potential risks of PPCPs in the surface waters of China, such as coastal waters, estuaries, rivers, lakes, and reservoirs.

Antibiotics

Antibiotics have been detected in surface waters throughout China, from southern to northern regions. The main categories included chloramphenicols, macrolides, fluoroquinolones, sulfonamides, tetracycline, trimethoprim, quinolones, and so forth. Erythromycin, sulfamethoxazole, and trimethoprim were widely detected in the offshore waters of Bohai Sea (north of China), coastal and offshore waters of Yellow Sea (north of China), and mariculture farms surrounding Hailing Island (south of China). The RQ value of dehydration erythromycin, sulfamethoxazole, and clarithromycin indicated high ecological risks to some sensitive aquatic organisms in Jiaozhou Bay of Yellow Sea, and low to medium potential risks to aquatic organisms in Yangtai Bay of the Yellow Sea and offshore waters of the Bohai and Yellow Seas (Zhang et al. 2013; Zhang et al. 2013; Chen et al. 2015). Studies on surface waters of Yangtze Estuary (which flows into the East China Sea) showed that sulfapyridine, sulfamethoxazole, sulfaquinoxaline, and erythromycin-H_2O could pose medium risks to sensitive aquatic organisms such as daphnia and fish (Yan et al. 2013; Shi et al. 2014). In the surface waters of Pearl River Estuary (which flows into South China Sea), sulfonamides levels suggested low to minimal risks, but ofloxacin, ciprofloxacin, and erythromycin could pose high risks to sensitive aquatic organisms (Xu et al. 2013).

In Wangyang River, a typical receiving river of effluents of WWTPs in north China, RQ values of 11 out of 14 detected antibiotics indicated high potential ecological risks to sensitive aquatic organisms, implying that wastewater discharge was an important source of antibiotic pollution (Jiang et al. 2014). In the south of China, the RQ values of sulfamethoxazole, erythromycin, and clarithromycin in the Yongjiang River suggested medium risks in the upstream regions and high risks in the midstream, which implies that the anthropogenic activities might be an important reason of antibiotic pollution (Xue et al. 2013). According to calculated RQ values, PPCPs in most of the investigated drinking water sources (like lakes and reservoirs) pose minimal ecological risks to aquatic organisms like algae, daphnia, and fish (Li et al. 2014; Zhu et al. 2014; Zhu et al. 2014).

Non-antibiotic pharmaceuticals

Non-antibiotic pharmaceuticals (such as non-steroidal anti-inflammatory drugs (NSAID), blood lipid regulators, antiepileptic drugs, beta blockers, cholesterol-lowering drugs, and analgesics) have also been detected in the surface waters of China. The dominant chemical during the whole year in Qingshan Lake (a drinking water source in Eastern China) was caffeine, but its RQ value indicated no potential risks (Zhu et al. 2013). Clofibric acid posed medium potential risks to aquatic organisms in the western part of Yangtze River (Yan et al. 2013). RQ values of diclofenac (a NSAID) in Pearl River system, Yellow River and Liao River indicated high potential risks to aquatic organisms (Wang et al. 2010; Zhao et al. 2010).

Hormones and personal care products

The estrogenic disrupting compounds were detected in surface waters of Liao River, Hai River, Pearl River, and Yellow River. Their RQ values indicated that the potential risks of those compounds were related to the wet and dry seasons in most surface waters. During the dry season, most of the potential risk levels were minimal to medium; while during the wet season, due to the runoff from surrounding regions, most of the potential risk levels were either higher than the dry season or raised from minimal or medium to high. However, most of the potential risk levels of the compounds observed in effluent-receiving rivers were high regardless of wet or dry seasons (Zhao et al. 2011; Jiang et al. 2012).

As for personal care products, musk fragrances and biocides were the main categories studied. HHCB and AHTN were detected in the body of freshwater fishes of Haihe River and Taihu Lake, and their bioaccumulation and bio-magnification in the freshwater food chain of Haihe River and Taihu Lake were also observed (Hu et al. 2011; Zhang et al. 2013). Disinfectants, azole fungicides and insect repellents were detected in the Dongjiang River, Pearl River, Liao River, Hai River, and Yellow River. RQ values of carbendazim (an azole fungicide) and triclosan (a disinfectant) detected in the Dongjiang and Pearl River systems indicated that they might pose high ecological risks to aquatic organisms (Zhao et al. 2010; Zhao et al. 2013; Chen et al. 2014).

Potential risks caused by PPCPs in the soil environment

Nineteen articles discussed the potential risks of PPCPs in soil within China. Fruit and vegetable farmland, and animal breeding farms were investigated in various studies.

Veterinary antibiotics

In some farms of northeastern China conducting concentration animal feeding operation, a study showed that tetracyclines, especially oxytetracycline in samples of animal feces might result in high ecological risk due to their high HQ values (Li et al. 2013). In the suburban areas of Tianjin, a study focused on agricultural soils receiving irrigation from WWTPs indicated low risks to organisms as the HQ values of the tested antibiotics were all below the trigger value (100 $\mu g \cdot kg^{-1}$) (Shi et al. 2012).

According to the standard recommended by the Veterinary International Conference on Harmonization (VICH) Steering Committee, in the Pearl River delta (located in the southern China), the levels of chlortetracycline, sulfameter, and quinolones in some samples were higher than the ecotoxicity trigger values (100 $\mu g \cdot kg^{-1}$) (Li et al. 2011). In a semitropical city of southern China, the HQ values of norfloxacin, ciprofloxacin, and enrofloxacin observed in some organic vegetable farms indicated low to medium potential risks to bacteria (Wu et al. 2014).

Hormones and personal care products

Following the standard recommended by the Environment Agency of United Kingdom, the level of 17beta-estradiol equivalents observed in some farms of Liaoning province might pose potential risks to local surface water systems (Liu et al. 2013). Under the same standard, the manure-borne estrogens in Beijing and Tianjin might also pose potential risk to local surface water systems (Li et al. 2013).

A research taken on a public park of Beijing, which received irrigation from reclaimed water of WWTPs, indicated that the accumulation of HHCB and AHTN in soils would take hundreds of years before reaching the levels to result in potential adverse effects to ecosystems (Wang et al. 2013).

Discussion

Based on the collected articles in this review, research results to date in China suggest that, under current regulatory guidelines and scientific information, the average potential risk status of PPCPs in both aquatic and soil environments in China are most often at low to medium levels. Some types of PPCPs identified in the environment may, however, pose relevantly high risks to the environment. Those were distributed in different regions across China. Many of the sample sites were at or near the coastal area of China, in regions with large populations and prosperous economies, while the number of studies on the environment of western China was limited. I next discuss some regulatory options for controlling PPCPs in the environment in China based on my review.

Mapping the national distribution of PPCP contamination

The regional distribution of the scientific research on assessing the risks of PPCPs in the environment mainly concentrated on the eastern part of China (see Figure 2.2). For example, only four of the sixty articles focused on the west of China (Yan et al. 2013; Yan et al. 2014) but two of them examined a city with a population of nearly 10 million. Population density and human activities (daily and agriculture) certainly play an important role on the level of concentration of PPCPs in the environment. That factor may also influence the potential risks of PPCPs indirectly. For example, the potential risks of PPCPs in rivers receiving effluents of WWTPs were significantly higher than other surface waters. Besides dense population and high levels of economic development in China, most of the important scientific research institutes and universities are located along the eastern coast of China and would typically choose to undertake research locally due to regional advantage, cost factors, and encouragement from local governments to do locally relevant work. This may help explain the lack of focused research on PPCPs in the western areas. To develop more effective and targeted environmental policy aimed at mitigating the adverse effects of PPCP pollution, it will be important to study the ecological risks posed by PPCPs throughout the whole of China.

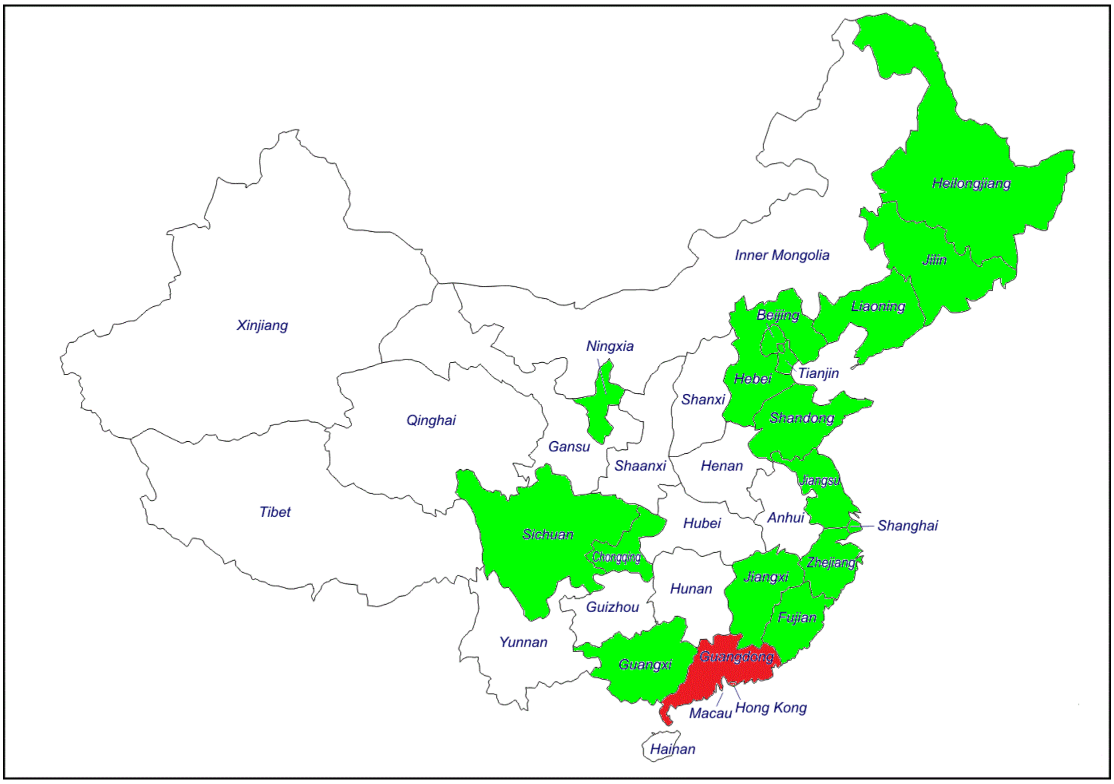

Figure 2. 2 Provinces of China that have taken risk assessment research on PPCPs in the environment according to our review. (The provinces of Guangdong have been mentioned by 11 research papers and was highlighted in red.)

Draw-back policy of unwanted and expired PPCPs

As it will be discussed in Chapter 3, the disposal of unwanted and expired PPCPs by households and healthcare centers is one of the main mechanisms in which PPCPs enter into the environment. As I discuss in chapter 3, the most common means of disposing of unwanted and expired PPCPs include throwing them as garbage, and flushing them by toilet or sink (Tong et al. 2011). Unwanted and expired PPCPs thrown as garbage will mainly be treated by landfill and their chemicals will enter into the underground waters and soils through landfill leakages, which can severely increase the potential risks of both water and soil environment caused by residues of PPCPs. Chemicals of unwanted and expired PPCPs flushed by toilet or sink will directly join the influents of WWTPs and finally enter into the environment through the effluents. According to my review, residues of chemicals of PPCPs in the effluents and receiving rivers of WWTPs usually have relevantly higher potential risks than other ground waters, and the flushed disposal way may aggravate the problem caused by PPCPs in the environment. A government supported national draw-back program of unwanted or expired PPCPs in China may help to control and reduce the amount of PPCPs entering into the environment through improper disposal practices.

To design and effective program and determine the feasibility of taking the draw-back program in China, first, we need to collect data related to the usage habits and disposal behaviors of PPCPs among Chinese households and healthcare centers by survey research and pilot programs in representative regions. Some developed countries (like UK, US) have taken such survey studies and pilot draw-back programs to examine the public disposal behaviors of unwanted and expired medicines (Bound and Voulvoulis 2005; Kotchen et al. 2009; Tong et al. 2011; Koshy 2013; Yang et al. 2015). While, to my best knowledge, beside my research, China have not taken any other survey studies on public disposal methods on research or policy decision-making purpose.

Cost benefit analysis is also necessary to help verify the feasibility of taking the draw-back program of unwanted or expired PPCPs in China. One of the possible way to assess the benefit of such a program is to ask the willingness to pay (WTP) of the public for the recycling program and calculate the gross value. The WTP question can add with the disposal behaviour survey, and the valuation survey instruments can be taken, such as the contingent valuation method (CVM). The costs of the draw-back program depend on the collection ways of unwanted and expired PPCPs. From existing literature, the mentioned recycling methods mainly include 1) returning the PPCPs to local pharmacies, 2) mailing the PPCPs back to certain institutions or original manufactories, 3) the government collecting the PPCPs door-by-door regularly, and 4) throwing the PPCPs under certain rubbish classification. Mail-back and garbage classification are impractical due to the realistic situation in China and the different categories of PPCPs, as the current national mail system may have to be modified and a rubbish classification system may need to be established, both of which need long time policy argument and discussion. Comparing with the door-by-door collection, returning the PPCPs directly to local pharmacies can significantly reduce labor costs and improve the time coordination, which is more feasible in China especially considering the population. To calculate the cost of the returning method, survey research with pharmacists are also needed.

Improvement of the removal technology of PPCPs in the WWTPs

Wastewater treatment plants (WWTPs) in both urban and rural areas are one of the major sources of PPCPs in the environment, and from the results of the review above we can see that the potential risks of PPCPs in receiving rivers of WWTPs are significantly higher than other streams of a river. To reduce the residues of PPCPs in the environment, improving the removal technology aimed at active chemicals of PPCPs during the treatment processes of the WWTPs might be a good policy choice. The main purpose of this option is to introduce advanced techniques to the WWTPs that can increase the removal rate of active chemicals of PPCPs in the effluent, which can reduce the concentration of PPCPs in the receiving water and lower the potential risks of PPCPs in water environment.

Like other emerging pollutants, there is no compulsory standards for the removal rates of PPCPs in the WWTPs, so their removal rates depend on the treatment techniques in the WWTPs and the categories of the PPCPs in their influent. The major steps of wastewater treatment processes are: (1) preliminary solids removal, (2) primary clarification, (3) secondary treatment, and (4) tertiary treatment. Preliminary solid removal and primary clarification are physical separation processes aimed at reducing large solid, sludge and floating materials, which could not reduce the chemicals of PPCPs in the wastewater. Secondary treatment is the main treatment procedure by using biological processes, and can remove around 90% organic substance in the wastewater. Chemicals of PPCPs in the wastewater should be removed at this stage. The common technologies used are conventional actived sludge (CAS) and membrane bioreactor (MBRs). Tertiary treatment is usually the last procedure and uses advanced treatment technologies, aiming to remove nutrient and disinfect the effluent by chlorination, UV radiation or ozone. Advance oxidation processes (AOPs) and reverse osmosis (RO) are adopted at this stage. Table 2.3 shows the steps and common treatment technologies of wastewater treatment processes in WWTPs (Gerrity and Snyder 2012).

To consider the feasibility of improving the wastewater treatment techniques in certain region, first, scientific research should be taken to investigate the occurrence and characteristics of PPCPs in the influent, effluent and receiving rivers of the targeted WWTPs, which can identify their current removal rate of PPCPs and the dominant categories of PPCPs in the effluent, and calculate their potential risk levels. If the current technology of the WWTPs cannot remove the high potential risk PPCPs properly, a more efficient technique aimed at removing the specific PPCPs may be considered.

Table 2. 3 - The steps and common techniques of wastewater treatment processes in WWTPs (Gerrity and Snyder 2012)

Step	Step names	Purpose	Common treatment techniques	PPCPs removed efficiency	PPCPs removed inefficiency
1	Preliminary solid removal	To remove large solid wastes in the influent	Physical phase separation	NA	NA
2	Primary clarification	To remove sludge and floating substances	Physical phase separation	NA	NA
3	Secondary treatment	To remove 90% of the organic matter in the effluent	conventional activated sludge (CAS) Membrane bioreactor (MBRs)	(up to 99%) hormones	Erythromycin (10%) Sulfamethoxazole (64%) Triclosan (68%)
4	Tertiary treatment	To remove untreated residues from the previous step (usual using advanced treatment technologies)	Advanced oxidation processes (AOPs) [To oxidize chemical pollutants by using highly reactive chemical species]	Most of the PPCPs	Meprobamate (less than 50%)
			Reverse osmosis (RO) [To separate the pollutants with clean water by using pressure to force effluent through a membrane]	ketoprofen, bisphenol A, triclosan, ibuprofen, and triclocarban	Unless not detected, removal rate>80% for most of the PPCPs

Besides the removal rate, the cost of new techniques is also an important requirement on determining which technology for removing PPCPs should be used. For example, according to Sun et al (2013), the highest concentrations of PPCPs observed in effluent of a WWTP in Xiamen (a coastal city of China) were ketoprofen, bisphenol A, triclosan, ibuprofen, and triclocarban. The most efficient technique to reduce those PPCPs is reverse osmosis (RO) (Zhou et al, 2008). Assuming the government decide to introduce this technique, the total annual costs of introducing the RO technique include the cost of treated water ($0.048 per gallon, Yeo 2010), and the operating and maintenance of the technique (including electricity, chemical cost, salary and training, reparation and network maintenance, $30,769 per year, Liang and de Vijk 2010). In Xiamen, a normal WWTP usually handle around 10 ton wastewaters per day, and there are 2 normal WWTPs and eight small WWTPs in this city. If we bring this amount to the analysis, the total cost would be more than $9.27 million per year.

Like the draw-back program, the benefit of introducing new techniques to WWTPs can be calculated by assessing the gross WTP of the public with survey research. After considering the result of the cost and benefit analysis, and the status of the potential risks of PPCPs, the government can make decision on whether taking this program.

Conclusion

As a field focusing on emerging pollutants, the scientific research on PPCPs in the environment are relatively new compared to the established scientific enterprise focused on traditional chemical pollution (e.g., heavy metals, insecticides) in China. My interests were the current risks status, levels, distribution and feasible regulation options of PPCPs in the environment in China.

By setting the search key words, we collected 2982 records initially from the database in both English and Chinese. After the title and abstracting screening, and judging from the whole passage of each article, finally, 60 records left for our reviewing. The sample sites of the selected articles are mainly on the coastal area of North and South China. The average conclusion through these articles is that due to the scientific uncertainty, the real effects or risks of PPCPs in the environment on ecosystems and human health is still unknown or potential. While some of the chemical compounds of PPCPs in the aquatic or soil environment might pose risks to sensitive microorganisms or bring antibiotic resistance which levels are various through low to high influenced by seasons (dry or wet), human activities (like aquaculture activities near the coastal water), locations (like if receiving discharge wastewater) , etc.

To test the feasibility of the three regulation options of PPCPs and conduct sufficient cost-benefit analysis, surveys facing households, pharmacists, manufactories and WWTPs should be taken in the future studies.

References

Arpin-Pont, L., Bueno, M., Gomez, E. and Fenet, H. (2014). Occurrence of PPCPs in the marine environment: a review. *Environmental Science and Pollution Research*: 1-14.

Ashbolt, N.J., Amézquita, A., Backhaus, T., et al. (2013). Human health risk assessment (HHRA) for environmental development and transfer of antibiotic resistance. *Environ Health Perspect* 121(9): 993-1001.

Bound, J.P. and Voulvoulis, N. (2005). Household disposal of pharmaceuticals as a pathway for aquatic contamination in the United Kingdom. *Environmental Health Perspectives* 113(12): 1705-1711.

Bu, Q., Wang, B., Huang, J., Deng, S. and Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. *J Hazard Mater* 262: 189-211.

Chen, H., Liu, S., Xu, X.-R., et al. (2015). Antibiotics in typical marine aquaculture farms surrounding Hailing Island, South China: Occurrence, bioaccumulation and human dietary exposure. *Marine Pollution Bulletin*(0).

Chen, Z.F., Ying, G.G., Liu, Y.S., et al. (2014). Triclosan as a surrogate for household biocides: An investigation into biocides in aquatic environments of a highly urbanized region. *Water Research* 58: 269-279.

Dai, G.H., Huang, J., Chen, W.W., et al. (2014). Major Pharmaceuticals and Personal Care Products (PPCPs) in Wastewater Treatment Plant and Receiving Water in Beijing, China, and Associated Ecological Risks. *Bulletin of Environmental Contamination and Toxicology* 92(6): 655-661.

Daughton, C.G. and Ternes, T.A. (1999). Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives* 107: 907-938.

de García, S.A.O., Pinto, G.P., García-Encina, P.A. and Irusta-Mata, R. (2014). Ecotoxicity and environmental risk assessment of pharmaceuticals and personal care products in aquatic environments and wastewater treatment plants. *Ecotoxicology* 23(8):

1517-1533.

Duan, Y.P., Meng, X.Z., Wen, Z.H. and Chen, L. (2013). Acidic pharmaceuticals in domestic wastewater and receiving water from hyper-urbanization city of China (Shanghai): environmental release and ecological risk. *Environmental Science and Pollution Research* 20(1): 108-116.

Fent, K., Weston, A.A. and Caminada, D. (2006). Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology* 76(2): 122-159.

Gerrity, D. and Snyder, S. (2012). Wastewater and Drinking Water Treatment Technologies. *Human Pharmaceuticals in the Environment: Current and Future Perspectives*. Brooks, W.B. and B.D. Huggett. New York, NY, Springer New York**:** 225-255.

González-Pleiter, M., Gonzalo, S., Rodea-Palomares, I., et al. (2013). Toxicity of five antibiotics and their mixtures towards photosynthetic aquatic organisms: implications for environmental risk assessment. *Water Res* 47(6): 2050-2064.

Halling-Sorensen, B., Nielsen, S.N., Lanzky, P.F., et al. (1998). Occurrence, fate and effects of pharmaceutical substances in the environment - A review. *Chemosphere* 36(2): 357-394.

Heberer, T. (2002). Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. *Toxicology Letters* 131(1-2): 5-17.

Hernando, M.D., Mezcua, M., Fernández-Alba, A.R. and Barceló, D. (2006). Environmental risk assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments. *Talanta* 69(2): 334-342.

Hu, Z., Shi, Y. and Cai, Y. (2011). Concentrations, distribution, and bioaccumulation of synthetic musks in the Haihe River of China. *Chemosphere* 84(11): 1630-1635.

Jiang, W.W., Yan, Y., Ma, M., et al. (2012). Assessment of source water contamination by estrogenic disrupting compounds in China. *Journal of Environmental Sciences-China* 24(2): 320-328.

Jiang, Y.H., Li, M.X., Guo, C.S., et al. (2014). Distribution and ecological risk of antibiotics in a typical effluent-receiving river (Wangyang River) in north China. *Chemosphere* 112: 267-274.

Kolpin, D.W., Furlong, E.T., Meyer, M.T., et al. (2002). Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: A national reconnaissance. *Environmental Science & Technology* 36(6): 1202-1211.

Koshy, S. (2013). Disposal of unwanted medications: throw, bury, burn or just ignore? *Int J Pharm Pract* 21(2): 131-134.

Kosma, C.I., Lambropoulou, D.A. and Albanis, T.A. (2014). Investigation of PPCPs in wastewater treatment plants in Greece: occurrence, removal and environmental risk assessment. *Sci Total Environ* 466-467: 421-438.

Kotchen, M., Kallaos, J., Wheeler, K., Wong, C. and Zahller, M. (2009). Pharmaceuticals in wastewater: Behavior, preferences, and willingness to pay for a disposal program. *Journal of Environmental Management* 90(3): 1476-1482.

Li, N., Zhang, X.B., Wu, W. and Zhao, X.H. (2014). Occurrence, seasonal variation and risk assessment of antibiotics in the reservoirs in North China. *Chemosphere* 111: 327-335.

Li, Y.W., Wu, X.L., Mo, C.H., et al. (2011). Investigation of Sulfonamide, Tetracycline, and Quinolone Antibiotics in Vegetable Farmland Soil in the Pearl River Delta Area, Southern China. *Journal of Agricultural and Food Chemistry* 59(13): 7268-7276.

Li, Y.X., Liu, S.F., Zhang, X.L., et al. (2013). The excretion features of manure-borne steroid hormones and their potential risk in the municipalities of China (in Chinese). *Acta Scientiae Circumstantiae* 33(8): 2314-2323.

Li, Y.X., Zhang, X.L., Li, W., et al. (2013). The residues and environmental risks of multiple veterinary antibiotics in animal faeces. *Environmental Monitoring and Assessment* 185(3): 2211-2220.

Liu, J.-L. and Wong, M.-H. (2013). Pharmaceuticals and personal care products (PPCPs): A review on environmental contamination in China. *Environment International* 59: 208-224.

Liu, S.F., Li, Y.X., Zhang, X.L., et al. (2013). Excretion of manure-borne steroid hormones and their potential risk in the three northeast provinces of China (in Chinese). *Environmental Science* 34(8): 3180-3187.

Peng, X., Huang, Q., Zhang, K., et al. (2012). Distribution, behavior and fate of azole antifungals during mechanical, biological, and chemical treatments in sewage treatment plants in China. *Science of the Total Environment* 426: 311-317.

Petrie, B., Barden, R. and Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. *Water Res* 72: 3-27.

Prosser, R. and Sibley, P. (2015). Human health risk assessment of pharmaceuticals and personal care products in plant tissue due to biosolids and manure amendments, and wastewater irrigation. *Environment international* 75: 223-233.

Rosi-Marshall, E.J., Snow, D., Bartelt-Hunt, S.L., Paspalof, A. and Tank, J.L. (2015). A review of ecological effects and environmental fate of illicit drugs in aquatic ecosystems. *Journal of Hazardous Materials* 282(0): 18-25.

Santos, L.H.M.L.M., Araujo, A.N., Fachini, A., et al. (2010). Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. *Journal of Hazardous Materials* 175(1-3): 45-95.

Shi, X., Zhou, J.L., Zhao, H., Hou, L. and Yang, Y. (2014). Application of passive sampling in assessing the occurrence and risk of antibiotics and endocrine disrupting chemicals in the Yangtze Estuary, China. *Chemosphere* 111: 344-351.

Shi, Y.L., Gao, L.H., Li, W.H., Liu, J.M. and Cai, Y.Q. (2012). Investigation of Fluoroquinolones, Sulfonamides and Macrolides in Long-Term Wastewater Irrigation Soil in Tianjin, China. *Bulletin of Environmental Contamination and Toxicology* 89(4): 857-861.

Sui, Q., Huang, J., Deng, S., Yu, G. and Fan, Q. (2010). Occurrence and removal of pharmaceuticals, caffeine and DEET in wastewater treatment plants of Beijing, China. *Water Research* 44(2): 417-426.

Sun, Q., Lv, M., Hu, A., Yang, X. and Yu, C.-P. (2014). Seasonal variation in the occurrence and removal of pharmaceuticals and personal care products in a wastewater treatment plant in Xiamen, China. *Journal of Hazardous Materials* 277: 69-75.

Ternes, T.A. (1998). Occurrence of drugs in German sewage treatment plants and rivers1. *Water Research* 32(11): 3245-3260.

Tong, A.Y., Peake, B.M. and Braund, R. (2011). Disposal practices for unused medications around the world. *Environment International* 37(1): 292-298.

Tong, C.L., Zhuo, X.J. and Guo, Y. (2011). Occurrence and Risk Assessment of Four Typical Fluoroquinolone Antibiotics in Raw and Treated Sewage and in Receiving Waters in Hangzhou, China. *Journal of Agricultural and Food Chemistry* 59(13): 7303-7309.

Wang, D., Sui, Q., Lu, S.-G., et al. (2014). Occurrence and removal of six pharmaceuticals and personal care products in a wastewater treatment plant employing anaerobic/anoxic/aerobic and UV processes in Shanghai, China. *Environmental Science and Pollution Research* 21(6): 4276-4285.

Wang, J., He, B. and Hu, X. (2015). Human-use antibacterial residues in the natural environment of China: implication for ecopharmacovigilance. *Environ Monit Assess* 187(6): 4514.

Wang, L., Ying, G.G., Zhao, J.L., et al. (2010). Occurrence and risk assessment of acidic pharmaceuticals in the Yellow River, Hai River and Liao River of north China. *Science of the Total Environment* 408(16): 3139-3147.

Wang, M.E., Peng, C., Chen, W.P. and Markert, B. (2013). Ecological risks of polycyclic musk in soils irrigated with reclaimed municipal wastewater. *Ecotoxicology and Environmental Safety* 97: 242-247.

Wu, X.L., Xiang, L., Yan, Q.Y., et al. (2014). Distribution and risk assessment of quinolone antibiotics in the soils from organic vegetable farms of a subtropical city, Southern China. *Science of the Total Environment* 487: 399-406.

Xu, W.H., Yan, W., Li, X.D., et al. (2013). Antibiotics in riverine runoff of the Pearl River Delta and Pearl River Estuary, China: Concentrations, mass loading and ecological risks. *Environmental Pollution* 182: 402-407.

Xue, B.M., Zhang, R.J., Wang, Y.H., et al. (2013). Antibiotic contamination in a typical developing city in south China: Occurrence and ecological risks in the Yongjiang River impacted by tributary discharge and anthropogenic activities. *Ecotoxicology and Environmental Safety* 92: 229-236.

Yan, C.X., Yang, Y., Zhou, J.L., et al. (2013). Antibiotics in the surface water of the Yangtze Estuary: Occurrence, distribution and risk assessment. *Environmental Pollution* 175: 22-29.

Yan, Q., Gao, X., Chen, Y.P., et al. (2014). Occurrence, fate and ecotoxicological assessment of pharmaceutically active compounds in wastewater and sludge from wastewater treatment plants in Chongqing, the Three Gorges Reservoir Area. *Science of the Total Environment* 470: 618-630.

Yang, C.H., Doshi, M. and Mason, N.A. (2015). Analysis of Medications Returned During a Medication Take-Back Event. *Pharmacy* 3(3): 79-88.

Zhang, Q.-Q., Ying, G.-G., Pan, C.-G., Liu, Y.-S. and Zhao, J.-L. (2015). Comprehensive Evaluation of Antibiotics Emission and Fate in the River Basins of China: Source Analysis, Multimedia Modeling, and Linkage to Bacterial Resistance. *Environmental Science & Technology* 49(11): 6772-6782.

Zhang, R.J., Tang, J.H., Li, J., et al. (2013). Occurrence and risks of antibiotics in the coastal aquatic environment of the Yellow Sea, North China. *Science of the Total Environment* 450: 197-204.

Zhang, R.J., Tang, J.H., Li, J., et al. (2013). Antibiotics in the offshore waters of the Bohai Sea and the Yellow Sea in China: Occurrence, distribution and ecological risks. *Environmental Pollution* 174: 71-77.

Zhang, X.L., Xu, Q., Man, S.K., et al. (2013). Tissue concentrations, bioaccumulation, and biomagnification of synthetic musks in freshwater fish from Taihu Lake, China. *Environmental Science and Pollution Research* 20(1): 311-322.

Zhao, J.-L., Zhang, Q.-Q., Chen, F., et al. (2013). Evaluation of triclosan and triclocarban at river basin scale using monitoring and modeling tools: Implications for controlling of urban domestic sewage discharge. *Water Research* 47(1): 395-405.

Zhao, J.L., Ying, G.G., Chen, F., et al. (2011). Estrogenic activity profiles and risks in surface waters and sediments of the Pearl River system in South China assessed by chemical analysis and in vitro bioassay. *Journal of Environmental Monitoring* 13(4): 813-821.

Zhao, J.L., Ying, G.G., Liu, Y.S., et al. (2010). Occurrence and risks of triclosan and triclocarban in the Pearl River system, South China: From source to the receiving environment. *Journal of Hazardous Materials* 179(1-3): 215-222.

Zhao, J.L., Ying, G.G., Liu, Y.S., et al. (2010). Occurrence and a screening-level risk assessment of human pharmaceuticals in the pearl river system, south china. *Environmental Toxicology and Chemistry* 29(6): 1377-1384.

Zhou, L.-J., Ying, G.-G., Liu, S., et al. (2013). Occurrence and fate of eleven classes of antibiotics in two typical wastewater treatment plants in South China. *Science of the*

Total Environment 452: 365-376.

Zhu, S.C., Chen, H. and Li, J.N. (2013). Sources, distribution and potential risks of pharmaceuticals and personal care products in Qingshan Lake basin, Eastern China. *Ecotoxicology and Environmental Safety* 96: 154-159.

Zhu, T.T., Duan, B.B., Song, Z.F. and Peng, S.H. (2014). Pollution characteristics and ecological risk assessment of antibiotics in Tiegang Reservoir in Shenzhen (in Chinese). *Ecology and Environmental Sciences*(7): 1175-1180.

Zhu, T.T., Song, Z.F., Yin, K.H. and Peng, S.H. (2014). Study on current situation and health risk of antibiotics residue in source water of Xili Reservoir in Shenzhen (in Chinese). *Environmental Pollution and Control* 36(5): 49-53,58.

CHAPTER THREE

Priority research questions on the environmental impacts of pharmaceutical and personal care products in China: insights from Chinese scientists

Xiaowen Wang[†], Peter Howley[†], Alistair B.A. Boxall[†], Murray A. Rudd[††*]

† Environment Department, University of York, Heslington, York, United Kingdom

†† Department of Environmental Sciences, Emory University, United States

* To whom correspondence may be addressed

Dr. Murray A. Rudd
Department of Environmental Sciences
Emory University
Atlanta, Georgia
30322
USA
Email: murray.a.rudd@emory.edu

Abstract

Pharmaceuticals and personal care products (PPCPs) can enter the environment through various routes. Given the emerging importance of PPCP contaminants in China, we used semi-structured interviews to probe Chinese scientists' perspectives, opinions, and attitudes on current and future PPCP research needs. We interviewed 14 respondents, nearly all of whom recognized the potential for adverse effects on human and ecosystem health even though current scientific evidence supporting harmful outcomes was viewed as tentative. Respondents identified poor disposal practices at hospitals and PPCP factories as important targets for focused control measures that could have high impact. Some thought public media could be used to build awareness of PPCPs among citizens; others thought that accurate information needed to be provided directly to policy-makers and regulators. To make appropriate and cost-effective decisions regarding PPCP discharge to the environment, cross-disciplinary cooperation will be needed between

Chinese environmental scientists, medical scientists, engineers, and economists.

Keywords: Antibiotics; emerging contaminants; pollution; PPCPs; research priorities

Introduction

Pharmaceuticals and personal care products (PPCPs) and their metabolites can enter the environment through various routes and pose risks to both aquatic and terrestrial organisms and, indirectly, to human beings (Daughton and Ternes 1999; Fent et al. 2006; Santos et al. 2010). These chemicals have now been detected in groundwater, surface water, drinking water, sewage effluent, landfill, and agricultural lands across the globe (Halling-Sorensen et al. 1998; Daughton and Ternes 1999; Heberer 2002; Eggen et al. 2010; Zhou et al. 2013; Kosma et al. 2014). An increasing number of countries have taken seriously the potential risks of PPCPs in the environment and research on various control options has followed, for instance on the removal of PPCPs in wastewater treatment plants and disposal of households' expired and/or unwanted PPCPs (Clara et al. 2005; Nakada et al. 2007; Glassmeyer et al. 2009; Kotchen et al. 2009; Tong et al. 2011; Thach et al. 2013; Kosma et al. 2014; Kwon and Rodriguez 2014).

While much PPCP research focus to date has been in the Western countries, consumption of PPCPs is growing rapidly in developing countries. Given large and increasing populations, rising economic affluence, shifts in food consumption patterns to more meat, lax controls on the use of antibiotics for human and veterinary purposes, the limited capacity of wastewater treatment plants to remove PPCPs from wastewater, and the potential for PPCP effects to manifest chronically as levels accumulate, there is a pressing need for more research in developing countries. China, for example, is a country with a high level of PPCP production and consumption (Zhou et al. 2013), a rapidly growing economy, and high levels of urbanization. The chemical components of PPCPs have been found in a variety of environmental media in different parts of China (Bu et al. 2013; Liu and Wong 2013; Wang et al. 2015). For example, the high usage of PPCP among urban residents has been reflected through the occurrences of residues of PPCPs in the effluents of municipal wastewater treatment plants and their receiving rivers (Dai et al. 2014). The Chinese government has begun to attach increasing importance to PPCPs in the environment (Wang et al. 2015).

Given the potential importance of, and lack of knowledge about, the overall state of research about PPCPs in China, there is a need for more information on research status and needs. Some of this has been addressed by Bu et al. (2013) in their systematic review, but the focus in their paper was on summarizing results from contamination studies that were often narrowly technical and highly focused geographically. To help identify the most pressing global knowledge gaps arising from the risks of PPCPs in the environment, Rudd et al. (2014) surveyed 535 environmental scientists from 57 different countries who were conducting PPCP-relevant research. The scientists ranked 22 important PPCP research priorities (first identified by Boxall et al. (2012)) and provided 171 additional PPCP research questions that they thought were also important. Relative to their Western counterparts, Rudd et al. (2014) found that Chinese scientists put more emphasis on "issues of managing risk profiles, effluent treatment, residue bioavailability and regional assessment" (p. 576).

We wanted to explore in more depth the issues that scientists deemed as important given the Chinese context of widespread water pollution, rapid growth in industrial production, and rapidly increasing household consumption of PPCPs. In this exploratory work, we conducted semi-structured, qualitative telephone interviews with Chinese experts conducting PPCP-related research. We used the research questions that Chinese scientists had earlier (Rudd et al. 2014) ranked as relatively important, relative to western scientists, to guide interviews and probed Chinese scientists' perspectives, opinions, and attitudes on current and future PPCP research needs. That could help to build initial understanding of the current PPCP research landscape in China and garner in-depth suggestions on how to prioritize and communicate environmental science.

Methodology

The aim of the research was to build understanding about current research priorities related to the effects or risks of PPCPs to both humans and ecosystems in China. To do this, we conducted semi-structured interviews (Kvale 2008; Hesse-Biber and Leavy 2010) with Chinese scientists, an appropriate methodology to gather from experts detailed information about current and emerging PPCP research priorities. Semi-structured interviews let interviewees provide information freely on issues in ways that survey research cannot. Such a qualitative research strategy can be useful when environmental problems are poorly structured and the objective is to selectively gain as much information as possible from experts. While results typically cannot be analyzed statistically, eliciting expert knowledge on a subject can provide an important baseline for future quantitative survey research (e.g., Asian members of the Society for Ecotoxicology and Chemistry will in September 2016 be involved in a ranking exercise that includes both PPCPs and other types of environmental contaminants – see http://www.setac-singapore2016.org/).

Table 3. 1 - Semi-structured guiding questions used in the interviews and their overall ranking from Rudd et al. (2014)

	Interview question	Global ranking	Chinese ranking
1	What are the risks to human health, arising from antibiotic resistance selection by PPCPs in the natural environment?	6	n/a
2	How can regions where PPCPs pose the greatest risk to environmental and human health, either now or in the future, be identified?	15	5
3	Do PPCPs pose a risk to wildlife such as mammals, birds, reptiles and amphibians?	10	n/a
4	If a PPCP has an adverse environmental risk profile what can be done to manage and mitigate the risks?	5	3
5	What effluent treatment methods are effective in reducing the effects of PPCPs in the environment while at the same time not increasing the toxicity of whole effluents?	2	1
6	How important are PPCPs relative to other chemicals and non-chemical stressors in terms of biological impacts on the natural environment?	7	2
7	How can risks of PPCPs in the environment be better communicated to the policy decision-makers and the public?	17	n/a
8	Future priorities	n/a	n/a

"n/a" means the question or the ranking of the corresponding question were not mentioned.

Seven of eight of our guiding questions (Table 3.1) for the interviews were first identified by Boxall et al. (2012) and ranked by Rudd et al. (2014). According to the results analysis of Rudd et al. (2014), most of the questions selected for our interviews in this study were viewed as being disproportionately important among the Chinese scientists, compared with their western counterparts. Our first and third interview questions had the highest global rankings among the 22 questions from Rudd et al. (2014) that were related to the risks of PPCPs in the environment to human health and wildlife health. The global ranking of our seventh interview question was the highest against other social science perspective questions from Rudd et al. (2014), and this question was also the only one directly related to the public and decision-makers within the 22 questions. The eighth was a general question about future research priorities. It is important to note that although some of the questions were ranked relatively low in overall rank in the prior ranking exercise, all of these questions had been through an extensive vetting of >400 candidate research questions (Boxall et al. 2012) and just to have made it to the final list is indicative of their international importance; our rationale for selecting all of our interview questions was based on prior analysis that highlighted those questions representing potential fulcrum issues that were particularly salient in China.

With respondents' permission, we recorded interviews by Skype, thus facilitating the preparation of interview transcripts and translation from Chinese to English for textual analysis. Interviews were conducted in a way such that respondents were answering questions in a professional capacity; informed consent was obtained and the research was approved by the Research Ethics Board at the Environment Department, University of York.

To identify the Chinese scientists and experts who had research experience on PPCP-related issues and who could represent the scientists and experts working in this field in China, the initial screening was to use the ISI Web of Science database to find the PPCP-related articles written by Chinese scientists and published in international ISI journals. The key words we chose to identify the initial articles were ["pharmaceutical* OR medicine* OR personal care product*"] AND ["soil* OR surface water* OR wastewater"], which could guarantee that all the research articles related to PPCPs in the water and soil environment were included. The initial screening generated 388 articles. We then took title screening with those articles (which purpose was to delete unrelated articles from initial screening by judging from their titles), which totally generated 66 PPCP-related articles and 62 authors who had e-mails with "ac.cn" or "edu.cn" (the code represents the academic e-mail address of Chinese researchers from universities or affiliated research institutions). As the research fields of some of the 62 authors might not be related to PPCP-related issues (e.g., cooperative projects could include experts from other fields), we conducted a profile screening by judging the profiles of all the 62 authors on their official web pages and only kept the authors whose official profiles indicated that their research fields were in PPCP-related issues, such as emerging pollutants, and environmental chemistry. We finally identified 23 candidate authors after the profile screening. Table 3.2 shows the steps and results of our sample screenings. We directly contacted the 23 candidate authors by e-mail or telephone to request and arrange interviews, which were all conducted via Skype. Interviewees were provided with the list of the guiding questions prior to the interview.

Table 3. 2 – Screening steps of the interview respondents

Screening steps	Search strategy or screening rules	Results
Initial screening	*Data sources*: ISI Web of Science database; Searched by: topic; *Language*: English and Chinese; *Regions*: China; *Period*: 2006 to 2014	388 articles
Title screening	Deleting articles unrelated to research of PPCPs in the environment by judging from their titles e.g., we deleted articles on medicine science, agriculture, and other kinds of pollutants	62 authors with academic email address (66 articles)
Profile screening	Reading the profiles of all the 62 authors on their official web pages, and choosing the suitable candidates whose research fields should be related to PPCP-related issues. Such as, fields in emerging pollutants, environmental chemistry	23 candidate authors

We compiled raw transcripts of the interviews (in Chinese) and classified that information into themes through multiple rounds of coding (Creswell 2012). NVivo software (QSR 2012) was used to store audio and text documents and, through coding of a priori and emergent themes, to identify commonalities and differences in opinions among the Chinese scientists.

Results

We completed full interviews with 14 respondents (denoted R1 to R14) who accepted our invitations, and the response rate was about 61%. Twelve were male and two female; six of the respondents were appointed at the equivalent of full Professor level and the other eight at Associate Professor level; all were natural scientists with either environmental chemistry, ecotoxicology, or ecology backgrounds. Eight were from government research institutes and six from universities. Because it is sometimes difficult to translate technical meanings directly from Chinese to English, when we use quotes we may have paraphrased slightly in order to convey respondents' intentions as closely as possible in English. Transcripts of respondents' answers translated in the most direct way are available from the corresponding author upon request. While the number of interviews was modest, such a number is typical in this type of qualitative work (judgement sampling) that seeks detailed information from experts in a field (Gysen et al. 2006); Interview-based studies typically use 5 to 25 respondents, and many studies would typically benefit from more in-depth consideration of opinions from experts rather than 'thin' analyses from more respondents (Kvale 2008).

The eight selected questions mainly focused on three dimensions relating to PPCPs in the environment: the risks of those PPCPs in the environment (Questions 1 and 3), the control and management of PPCPs (Question 2, 4, 5, and 7), and the state of scientific work of PPCPs (Question 6 and 8). Table 3.3 summarized the results of our findings.

Question 1: Risks arising from antibiotic resistance

In response to the question "What are the risks to human health, arising from antibiotic resistance selection by PPCPs in the natural environment?", ten respondents expressed belief that antibiotic resistance in organisms exposed to PPCPs in the natural environment could put human health at risk. Six respondents also specifically mentioned potential risks for ecosystems and two mentioned potential risks for livestock. Respondents recognized that there was little evidence linking the existence of PPCPs in the environment with the presence of antibiotic resistant bacteria in the natural environment, thus highlighting the importance of more experiments before any conclusions are made about the risks of PPCPs in the environment to human health causing by antibiotic resistance. Despite their caution regarding linking PPCPs, antibiotic resistance, and human health, one respondent (R5) acknowledged that "research on antibiotics has been taken seriously in China as the usage of antibiotics is really huge here, perhaps half the usage of the whole world" and that antibiotic residues had been found in freshwater and soils nationally.

One respondent noted that the potentially adverse effect of antibiotic resistance in the farm food chain had the potential to influence human health and that bacterial diversity may also be a problem (R5). Another (R13) thought that "antibiotic resistant genes might impose a huge impact on many aquatic ecosystems in the future… because one feature of PPCPs is that they have various transformation reactions in the aquatic environment." There was also emphasis (R10) on the need for basic data to conduct risk assessments and the great differences between regions within China (e.g., Shanghai and Beijing are much different). Part of the difficulty with risk assessments is that the burgeoning Chinese

PPCP manufacturing sector does not consider the long-term effects of PPCPs in the environment: "When pharmaceutical plants and manufacturers research and develop new PPCPs, they could not consider everything or undertake long-term experiments… While for the short run the risks are low… what we need are long-term experiments during which we could see more evidence of risks of PPCPs in the environment" (R10).

Table 3. 3 The summarization of the findings from our interview with Chinese scientists

Aspects	No.	Questions	Main opinions of experts
Risks	1	Antibiotic resistance	Risks to human health Risks to ecosystems Risks to livestock More evidence needed
	3	Risks to wildlife	PPCPs will pose a risk to wildlife More evidence needed
Management	2	Identifying at-risk regions	Emission levels of PPCPs Technology available for investigation Data from epidemiological studies The uses of PPCPs and economic growth of China
	4	Mitigating risks	To control the sources of PPCPs besides the endpoints Science-policy interface – the duty of scientists Ecosystem protection VS medical treatment
	5	Effluent treatment	The innovations to reduce PPCPs specifically The influence of the complicated wastewater system The less of cost-effective methods to reduce PPCPs completely
	7	Risk communication	With the public – the double-edge sword of social media With decision-makers – to assemble and provide accurate data
Research	6	Importance compared with other stressors	PPCPs are the same important as other stressors (5/14) PPCPs may be less important than other stressors (6/14)
	8	Future research in China	More scientific experiments Technological development

Question 2: Identifying at-risk regions

The second question, "How can regions where PPCPs pose the greatest risk to environmental and human health, either now or in the future, be identified?" elicited responses from more than half of the respondents regarding three different factors needed to answer this question: the emission levels of the PPCPs of the region; the technology available for detecting the levels of PPCPs in the environment; and data collected from epidemiological studies. Additionally, one respondent (R1) highlighted the importance of considering the relationship between PPCP use and economic growth in China: "PPCPs are different from traditional pollutants as the use of PPCPs will increase with increasing economic development status." Several respondents thought that this question would be difficult to answer as levels of PPCPs in the environment are low and there were no Chinese risk threshold standards currently available to help judge the risk level (R7). In addition, it would be difficult to assess regional risk simply using concentration levels of PPCPs because of differences in environmental conditions, dilution effects, and differences in the mobility and persistence of various PPCPs (R13). One respondent (R2) also emphasized the importance of wastewater from pharmaceutical manufacturing and hospital wastewater treatment plants so that risk assessment models could be developed to help identify the risks of PPCPs in the environment for specific regions.

Question 3: Wildlife risks

Ten of the 14 respondents believed that PPCPs will pose a risk to wildlife but the four others thought that more evidence was needed to assess those risks. Many compounds in personal care products have hormonal effects which may affect wildlife reproduction in the long run (R13). The respondents who doubted that risks of PPCPs to wildlife were substantial thought that the level of PPCPs in controlled experiments was far higher than the level of PPCPs in the natural environment (R4). One respondent (R10) also emphasized that risk and harm are different, and that while PPCPs may pose some risk that, given the concentration levels typically seen in China there would not be significant harm to wildlife species.

Question 4: Managing and mitigating risk

Most of the respondents said that the question "If a PPCP has an adverse environmental risk profile what can be done to manage and mitigate the risks?" should be considered from two perspectives, according to both science and management. For instance, "many environmental problems in China are, in fact, management problems, not technology problems…" (R3). The respondents intimated that interventions targeting sources of PPCPs were potentially more effective than efforts focusing on endpoints like surface waters. "Human medicines are from hospitals and factories, and pollution originates from their wastewater […thereby implying that] we should use more efficient treatment methods to reduce their access to the environment... [and that] for large farms, we should collect and treat wastewater together, avoiding their direct discharge into the natural water and thus control the problems at their source" (R10). Some respondents emphasized measures to control the sources of PPCP release into the environment were particularly important: "besides daily PPCP use, the source of most of the PPCPs is the discharge from industry, such as pharmaceutical plants – from the management point of view, wastewater discharge from pharmaceutical plants must be made to meet standards" (R3); "because the pharmaceutical industry is a relatively large industry in China, their waste emissions must be controlled" (R6); and "it is a complicated system, but we believe that the source control methods such as prescription management and centralized waste processing are very important" (R13).

From a science-policy interface perspective, one respondent felt that "scientists should provide some data and the basic threshold values, then it is up to the government and environmental sectors to take measures [to control that pollution]" (R1), a sentiment echoed by other respondents in the interviews. Some respondents also put emphasis on the role of communicating scientific information to the public as a means of stimulating political interest in the issue. One respondent (R2) stated that "I personally think it is a long-term process as we scientists can just do our research, study, report and show our results truthfully, and then hope those results gain the public's attention – when they realize the severity of this problem then they might seek some alternatives."

Tensions were noted regarding the relative importance of ecosystem versus human health. One respondent (R5) summed this up: "I think, currently, from the perspectives of human beings, society as a whole and government, the first consideration should be whether pharmaceuticals can cure disease, rather than their impacts of those pharmaceuticals on the environment." He added that wastewater treatment technologies might be applied when there are substantial environmental risks in order that human benefits could be maintained. Another (R11) thought that "if some PPCPs really pose risks to human health, scientists might try to develop some substitutes for patients to reduce the risks".

Question 5: Effluent treatment

In answer to the question "What effluent treatment methods are effective in reducing the effects of PPCPs in the environment while at the same time not increasing the toxicity of whole effluents?", respondents primarily focused on the potential for innovations that could specifically help reduce PPCPs at wastewater treatment plants. Options included reverse osmosis, ozone oxidation, chlorine or ultraviolet disinfection, advanced oxidation processes, and membrane treatment.

Respondents mostly recognized that there are currently no perfect methods that could cost-effectively reduce all PPCPs compounds and leave no by-products, that detection at the appropriate level is challenging in its own right, and that, due to conversion of transformation of chemical compounds of PPCPs in the environment, the characterization of toxicity was difficult. As one scientist put it, "Given the various classes and significant different chemical properties of PPCPs, it is impossible to deal with them by just one method." Another (R13), stated that "because the wastewater system is very complicated and it is hard to tell whether there was a decrease of toxicity associated with a decreased level of PPCPs." Further, there was recognition of the role that economics would play in PPCP treatment. For example, "…in my building we could use membrane technology or for my community we could use advanced oxidation, which could remove 100% of these pollutants, but for the entire region, like Shanghai or the whole country, this is economically unrealistic" (R2).

Question 6: Relative importance of PPCPs compared to other stressors

In response to the question "How important are PPCPs relative to other chemicals and non-chemical stressors in terms of biological impacts on the natural environment?", six of 14 respondents thought that the effects or risks of PPCPs in the environment were less important than the traditional chemical stressors. Some of relevant observations included: "Our main goal is traditional pollutants, which have received more attention than PPCPs, due to their large impacts." (R4); "compared with traditional pollutants, the pollution status of the whole category of PPCPs are certainly not so severe and their impacts are not so direct… PPCPs will not directly lead to consequences which are easy to see, their influence are more chronic and subtle" (R10); and "… in the long run the adaptability of species to PPCPs may bring some ecosystem changes and affect population structure – these need further proof and now only exist in theory but this is our worry.” (R14).

On the other hand, five out of 14 respondents said that the effects or risks of PPCPs in the environment were as important as for other chemicals or non-chemical stressors. The most important feature of PPCPs is their persistence in the environment: “PPCPs can degrade and metabolize in the environment… [and] because human beings use and are exposed to them every day, when it comes to the long-term effects, PPCPs may produce similar results like some of the POPs… Continuous exposure to them in the environment could have a huge impact on human health” (R11).

Question 7: Risk communication

All 14 respondents, in response to the question “How can risks of PPCPs in the environment be better communicated to the policy decision-makers and the public?”, expressed their belief that relevant scientific research on PPCPs in the environment should first assemble evidence and provide technical support for policy decisions. On the other hand, their attitudes regarding the communication with the policy decision-makers and the public varied. Even though half of the respondents recognized the public media as central for information dissemination to the public about the risks of PPCPs in the environment, there was also fear that the Chinese media overstates the risks of PPCPs and could adversely affect efforts to solve problems. According to one respondent (R2), “The only thing that scientists can do is to study and report their results truthfully… Scientists would like the public to be aware of the potential risks of PPCPs, but the public media sometimes tends to exaggerate during their reporting.” Another (R3) recalled the example of a researcher who presented results that showed estrogen had been detected in Beijing water: the popular media “reported that the drinking water of Beijing citizens containing birth control pills.”

For communication with the policy- and decision-makers, nearly all of the experts believed that the only thing they could do was to provide accurate data and advice. There was a pragmatic bent among respondents: one suggested that from a societal perspective, “we should realize that not all of environmental problems can be solved immediately and that governments have priorities to address problems caused by traditional pollutants before gathering evidence about the emerging pollutants" (R3). Another (R5) added that "both the national and local environmental protection departments are currently aware of the existence of PPCPs in the environment, but that because no specific standards related to PPCPs are in place, it is… impossible for them to take action."

Question 8: Key future research for China

The final guiding question for the interviews was "What do you think are key future scientific research needs for PPCPs in the environment in China?" The answers to this question mainly focused on scientific experiments to support pharmaceutical research and development, and technological development for detecting and reducing PPCPs in the environment. Respondents highlighted a number of topics relating to the effects of PPCPs on ecosystem, for example:

> "We should pay more attention to the biological communities and the effects of PPCPs on the whole ecology not just its toxicology" (R3),
>
> "Both environmental behaviour and treatment methods of PPCPs are important – currently, the main need is to understand the fate and transformation of PPCPs as they have already been found in natural waters" (R7),
>
> "The most import thing is to understand the level and characteristics of pollutants – then, integrating those data with the toxicological data, we could identify the risks of PPCPs on human health and ecology" (R10),
>
> "The amount of PPCPs discharged into the environment is substantial, so the problem of PPCPs in the environment mainly relates to wildlife – wildlife are complicated, as the physiological processes of different wildlife are totally different and it is really difficult to identify the effects of PPCPs on wildlife by analogy from research aimed at humans... The effects of PPCPs on birds, reptiles, and amphibians are all unknown" (R11),

> “There are actually two important aspects for ecological risk assessment, one focusing on the transformation of the pollutants in the environment and the other on the change of toxicity after transformation” (R12).

From a technological perspective, respondents mentioned that detection techniques for PPCPs need to be taken more seriously and that more effective technologies for reducing PPCPs during wastewater treatment should be developed. For example, “I think that from the detection rate of some kinds of medicines (like anti-inflammatory analgesic medicines, psychotropic substances and other pharmaceuticals) we could deduce that they are not as important as antibiotics and estrogens in China” (R5). Another (R4) emphasized the importance of detection and uncertainty: “if the concentration of a substance is very low in the environment, we have to use high sensitivity detection methods… The more trace the substance is, the more that external factors will affect outcomes when we are trying to examine subtle mechanisms (e.g., like toxicity, antibiotic resistance mechanisms)… [and] so there will be a lot of uncertainty.”

Discussion

Based on the results of our interviews, we suggest that most of the Chinese scientists interviewed shared similar opinions on numerous scientific or technical aspects issues regarding PPCPs in the environment in China. For example, nearly all of them tended to believe that antibiotic resistance selection by PPCPs in the environment could impose risks to human health, even though current scientific evidence supporting this view was tentative. They also shared opinions that risks of PPCPs to wildlife were possible but yet to be demonstrated. Regarding the potential for effluent treatment methods to reduce PPCPs while not increasing toxicity levels of whole effluents, respondents mentioned more or less the same techniques and most of them stated that these were currently prohibitively expensive given the current state of technology.

The respondents’ ideas on management of PPCPs in the environment were more divergent. For example, their attitudes on communicating the risks of PPCPs to the public were not consistent, as some of them preferred to use the public media to build awareness of PPCPs among citizens, while others thought that accurate information needed to be provided directly to policy-makers and regulators. Based on our interview responses and comparing them with the relevant international literature, we suggest that the following themes may be important to examine in more detail in China.

Themes arising among Chinese scientists

Scientific uncertainty regarding PPCPs in the environment

During our interviews with the Chinese scientists, we found that nearly half of them believed that scientific research and evidence on the effects of PPCPs in the Chinese environment are still limited and more experiments are thus needed before making any decisions on dealing with PPCPs in the environment. The Chinese scientists' attitudes on the scientific uncertainty and lack of scientific evidence of the specific effects or risks of PPCPs in the environment are in line with international perspectives (Williams and Brooks 2012; Arpin-Pont et al. 2014). Our respondents believed that, even though PPCPs are used nearly every day by everyone and could be deemed as a kind of persistent pollutant in the environment, evidence of their potential harm was lacking. The issue of long-term chronic risk (and risk perception) is also important in other fields (e.g., Morgan and Henrion (1990); Krebs (2005)). With regards specifically to PPCPs, areas of uncertainty include: the long term risks on human health from individual consumption of food containing PPCPs (Love et al. 2012; Boonsaner and Hawker 2013; Dodgen et al. 2013; Liu and Wong 2013); the chronic effects of drug resistance on environment and human health (Baran et al. 2011; Andersson and Hughes 2012; Williams and Brooks 2012; Adachi et al. 2013); and the chronic risks of PPCPs in the environment to ecosystem function and services (Rosi-Marshall and Royer 2012; Dai et al. 2014; Rosi-Marshall et al. 2015; Shaw et al. 2015).

Attitudes on whether the effects and risks of PPCPs in the environment are substantive may not only impact scientists' research priorities on the PPCPs in the environment, but also influence the government's opinions and actions on management and treatment of those PPCPs. The scientists who viewed PPCPs in the environment as trace pollutants that posed no verifiable risk to human health also thought traditional pollutants like metals were more severe in China, requiring immediate solutions. While scientists and regulators in Western countries have adopted more precautionary approaches to environmental contaminants, the view of Chinese scientists was pragmatically-oriented, with implicit or explicit recognition of the economic implications of different approaches to control them.

Public awareness of PPCPs in the environment

Besides the difficulty of establishing criteria for policies and regulations to control and manage PPCPs in the environment, building awareness among the public of the effects and risks of PPCPs was viewed as a challenge. Effluent from municipal wastewater treatment plants, agricultural wastewater, and leaching of landfills to groundwater reservoirs are important sources of PPCPs in the environment (Liu and Wong 2013), and are closely related to human behavior. It may therefore be prudent to build awareness among the public about the potential effects and risks of PPCPs in the environment and engage them in efforts to help control PPCP release to wastewater and solid waste systems at the source. However, due to the scientific uncertainty (i.e., unclear links to human health), the fact that PPCPs occur at trace levels in the environment, and the daily necessity of (and lack substitutes for) many of the chemicals in PPCPs (Liu and Wong 2013), it may be difficult to explain to the public how their daily choices could affect the environment and that the presence of PPCPs in the environment might lead to health risks in the future. Understanding how information provision, held worldview, core cultural values, and the perceived salience of environmental threats to well-being have been studied extensively in other fields (e.g., Stern (2000); Henry and Dietz (2012)). Given the potential importance of the Chinese consumer in designing interventions to curtail the release of PPCPs into the environment, there is a pressing need for future research that helps build understanding on the potential behavioral shifts and the effect of initiatives such as take-back programs for expired pharmaceuticals in China. Urban initiatives may be particularly important given population concentration, pollution output, and the potential to implement the types of interventions that require high population densities to be economically viable (e.g., take-back programs, specialized wastewater treatment technologies, etc.).

The scientists we interviewed mentioned the power of the modern media – television programs, newspapers, radios, and social media – to help communicate science. However, even though media can disseminate information about potential effects and risks of PPCPs in the environment to the public, there are still issues that need to be considered.

First, scientists expressed concern about exaggerated reporting. Some scientists were concerned that when, for example, news outlets reported that Beijing drinking water contained birth control pills, that citizens education and awareness of the true scientific concerns may be lost. From a theoretical perspective, encouraging pro-environmental behavior requires that people understand the threats or risks they might face if their behavioral intent is to change and, even then, other social and institutional constraints can prevent individuals following through on their behavioral intent and actually taking action (Stern 2000). Second, scientists were concerned that uncertainty among Chinese citizens regarding the potential implications of PPCPs in the environment may affect the governments' willingness to take action. This suggests scientists thought that there was a demand-side pull for policy and regulation rather than a policy supply-side push from governments taking a broader societal perspective on the public good. The relationship between academia and government has been changing rapidly in China (Serger et al. 2015) but it is generally viewed that only elite scientists have substantial influence on government science-based policy and regulatory decisions. Rank and file scientists working on PPCPs in the environment may not have a realistic view of the science-policy interface process and highlights the potential importance in China, as it is in the West (Lawton and Rudd 2013), of senior and connected scientists as mediators at the science-policy interface.

The relationship between media-driven citizen complaints and the level of attention that different levels of government devote to those issues is unclear in China. The level of awareness of environmental problems has increased greatly among Chinese citizens over the last decade (Xi et al. 2015) but some local governments, especially in rural and developing areas, still compromise environmental and human health for the sake of economic development. Even when regulations are in place and there is intent to enforce them, the scale of monitoring necessary to discourage pollution overwhelms government capacity to do so (e.g., Wang et al. (2008)).

Government position on controlling and reducing PPCPs in the environment

Governments have multiple options for controlling PPCP release into the environment; they could, for example, set standards for PPCP waste discharge from factories and hospitals, regulate or encourage city families to recycle or dispose responsibly of unwanted PPCPs, more closely regulate the use of veterinary antibiotics in large farms, and impose discharge standards on wastewater and solids disposal. To make effective and efficient choices, governments need evidence and engagement from scientific experts. In China, there are mechanisms for scientists to participate in providing policy-making advice, such as local and national Chinese People's Political Consultative Conference (CPPCC), and via the Chinese Academy of Science (CAS) and its affiliates.

In other realms of scientific research internationally, a variety of work has been done on scientists' willingness to engage with policy-makers and their views on their role at the science-policy interface. For example, in a global survey of ocean scientists, Rudd (2015) found three clusters of scientists who varied in their perspectives, the largest of which were 'evidence providers', who believed their job ends once scientific evidence is prepared and presented. In our interviews, all respondents could be classified as evidence providers. When scientists take on this role, it does mean that there must be important intermediaries at the science-policy interface in China, playing a role in identifying science perceived as important (for any of a variety of possible reasons) and translating it for government officials. However, the process by which science reaches the policy world is not clear in the environmental contaminants realm as there is functionally no research on the science-policy interface. There is thus a need to better understand how high-quality scientific evidence could support Chinese policy-makers and how various technical and managerial solutions and interventions may vary in effectiveness and cost.

Currently much of the Chinese research on PPCP-related issues seems to largely focus on the occurrence, fate, and effects of PPCPs in the environment and has focused on only a few PPCP classes such as antibiotics. While one respondent (R4) called for "cooperation with medical experts – as environmental scientists, we are not really familiar with medical science", there appeared to be limited appreciation of need for transdisciplinary PPCP research (i.e., crossing disciplines and organization types). Wang et al. (2015), however, provided a noteworthy exception to this view, calling for cross-disciplinary efforts to implement eco-pharmavigilance initiatives in China. China's strong focus on high-profile scientific advances and stratification of research institutions (Serger et al. 2015), in combination with an evidence provider orientation among scientists, may mean that opportunities for cross-cutting environmental research are, however, constrained in the near term.

Economic growth and PPCP use

As a result of its growing population and sustained economic growth, China has become one of the world's largest markets of PPCPs. A 2013 survey calculated that Chinese citizens consumed around 162,000 tons of antibiotics (Zhang et al. 2015) and media (finance.people.com.cn/n/2015/0118/c1004-26405365.html) reported that annual gross sales of cosmetics in China totaled more than US $32 billion (8.8% of the global cosmetic market and second in size only to the United States). As the Chinese economy continues to expand, market demand from more affluent consumers will likely accelerate consumption and, therefore, discharge of PPCP waste products into the environment. Further, as affluence increases, diets are likely to continue to shift in favor of more meat products (Pingali 2007), implying increasing levels of agricultural antibiotics make their way into human food supplies via residuals in food and via wastes discharged to waterways and soils. A few local government and environmental organizations in China have taken actions on voluntary recycling of expired and unwanted pharmaceuticals, and government has been supportive of take-back programs (Wang et al. 2015). To help justify recycling initiatives, quantifying the monetary costs and benefits of different methods on controlling PPCP release into the environment will be necessary. Given the potential for PPCPs to have chronic effects on ecological structure and function, the costs and benefits of pollution and control measures on a spectrum of ecosystem services and human health risks should be quantified.

Study limitations

As China is one of the largest PPCP producers and consumers in the world, understanding the status of current scientific research and emerging research priorities in China is crucial. Therefore, in order to take an initial step in that direction, our research focused on the opinions and attitudes of a selection of Chinese scientists and experts working on PPCP-related issues, whose disciplines were mainly on emerging pollutants, environmental chemistry, ecological risk assessment, and environmental restoration, and could represent the scientists of this research field. We recognize that different issues may have been raised by different interviewees but were encouraged to (1) see the degree of consistency in responses to some questions among our interviewees, and (2) the general alignment of Chinese and international scientists on several of the technical issues raised by this research. While it would have been preferable to interview more scientists, there were a number of challenges that we faced in conducting this type of research. Recruiting potential respondents was a particular challenge, due to their busy research schedules. Many experts did not respond to email interview requests and could not be contacted by telephone. Getting busy professionals to participate in interviews can be challenging in other fields as well, where several studies reported similar respondent participation rates to our research (e.g., Pieters et al. (2012); Soon et al. (2012)). To our best knowledge, this was the first research involving Chinese expert interviews on PPCPs and, despite some potential gaps that we missed with only 14 scientists, our research could represent the experts opinions of China and should provide a valuable and novel first step to better understanding research priorities regarding PPCPs in the environment.

Conclusions

On the basis of our telephone interviews with Chinese scientists actively researching PPCPs in the environment and publishing research in international journals, we found that those scientists recognized the potential for adverse effects on human and ecosystem health arising from the discharge of PPCPs to the environment. However, there were still many uncertainties that the scientists expressed, so additional research needs to be taken to provide more conclusive evidence of risk and harm to ecosystem and human health in China. PPCP consumption in China is already enormous and will likely continue to grow quickly given population growth and strong economic development. There may be practical limits to how policy-makers can set standards on PPCP production and consumption, and to the rollout of programs to enhance recycling of expired consumer products. Thus, as several of our interviewees stressed, technological development may be important for controlling PPCP discharge in wastewater from treatment plants. Additionally, respondents identified poor disposal practices at hospitals and PPCP factories as important targets for focused control measures that could have a relatively high impact. To make appropriate and cost-effective decisions regarding the level of PPCPs that are discharged to the environment in China, cross-disciplinary cooperation will be needed between environmental scientists, medical scientists, engineers, and economists. The pathways that facilitate the movement of new and credible scientific evidence across the science-policy interface, directly or indirectly – via public pressure – to the policy sphere, also needs clarification and further research if Chinese citizens' exposure to PPCPs and potential risk factors are to be maintained within acceptable margins over time.

Acknowledgments

We sincerely thank the interviewees who shared their valuable time and experience for this research.

References

Adachi, F., Yamamoto, A., Takakura, K.-I. and Kawahara, R. (2013). Occurrence of fluoroquinolones and fluoroquinolone-resistance genes in the aquatic environment. *Science of the Total Environment* 444(0): 508-514.

Andersson, D.I. and Hughes, D. (2012). Evolution of antibiotic resistance at non-lethal drug concentrations. *Drug Resistance Updates* 15(3): 162-172.

Arpin-Pont, L., Bueno, M., Gomez, E. and Fenet, H. (2014). Occurrence of PPCPs in the marine environment: a review. *Environmental Science and Pollution Research*: 1-14.

Baran, W., Adamek, E., Ziemiańska, J. and Sobczak, A. (2011). Effects of the presence of sulfonamides in the environment and their influence on human health. *Journal of Hazardous Materials* 196(0): 1-15.

Boonsaner, M. and Hawker, D.W. (2013). Evaluation of food chain transfer of the antibiotic oxytetracycline and human risk assessment. *Chemosphere* 93(6): 1009-1014.

Boxall, A., Rudd, M.A., Brooks, B.W., et al. (2012). Pharmaceuticals and personal care products in the environment: what are the big questions? *Environmental Health Perspectives* 120(9): 1221-1229.

Bu, Q., Wang, B., Huang, J., Deng, S. and Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. *J Hazard Mater* 262: 189-211.

Clara, M., Strenn, B., Gans, O., et al. (2005). Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants. *Water Research* 39(19): 4797-4807.

Creswell, J.W. (2012). Qualitative inquiry and research design: Choosing among five approaches, Sage.

Dai, G.H., Huang, J., Chen, W.W., et al. (2014). Major Pharmaceuticals and Personal Care Products (PPCPs) in Wastewater Treatment Plant and Receiving Water in Beijing, China, and Associated Ecological Risks. *Bulletin of Environmental Contamination and Toxicology* 92(6): 655-661.

Daughton, C.G. and Ternes, T.A. (1999). Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives* 107: 907-938.

Dodgen, L.K., Li, J., Parker, D. and Gan, J.J. (2013). Uptake and accumulation of four PPCP/EDCs in two leafy vegetables. *Environmental Pollution* 182(0): 150-156.

Eggen, T., Moeder, M. and Arukwe, A. (2010). Municipal landfill leachates: a significant source for new and emerging pollutants. *Science of the Total Environment* 408(21): 5147-5157.

Fent, K., Weston, A.A. and Caminada, D. (2006). Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology* 76(2): 122-159.

Glassmeyer, S.T., Hinchey, E.K., Boehme, S.E., et al. (2009). Disposal practices for unwanted residential medications in the United States. *Environment International* 35(3): 566-572.

Gysen, J., Bruyninckx, H. and Bachus, K. (2006). The Modus Narrandi A Methodology for Evaluating Effects of Environmental Policy. *Evaluation* 12(1): 95-118.

Halling-Sorensen, B., Nielsen, S.N., Lanzky, P.F., et al. (1998). Occurrence, fate and effects of pharmaceutical substances in the environment - A review. *Chemosphere* 36(2): 357-394.

Heberer, T. (2002). Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. *Toxicology Letters* 131(1-2): 5-17.

Henry, A.D. and Dietz, T. (2012). Understanding environmental cognition. *Organization & Environment* 25(3): 238-258.

Hesse-Biber, S.N. and Leavy, P. (2010). The practice of qualitative research. London, Sage Publications.

Kosma, C.I., Lambropoulou, D.A. and Albanis, T.A. (2014). Investigation of PPCPs in wastewater treatment plants in Greece: occurrence, removal and environmental risk assessment. *Science of the Total Environment* 466: 421-438.

Kotchen, M., Kallaos, J., Wheeler, K., Wong, C. and Zahller, M. (2009). Pharmaceuticals in wastewater: Behavior, preferences, and willingness to pay for a disposal program. *Journal of Environmental Management* 90(3): 1476-1482.

Krebs, J.R. (2005). The Croonian Lecture 2004 Risk: food, fact and fantasy. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 360(1458): 1133-1144.

Kvale, S. (2008). Doing interviews, Sage.

Kwon, J.-W. and Rodriguez, J.M. (2014). Occurrence and Removal of Selected Pharmaceuticals and Personal Care Products in Three Wastewater-Treatment Plants. *Archives of environmental contamination and toxicology* 66(4): 538-548.

Lawton, R.N. and Rudd, M.A. (2013). Crossdisciplinary research contributions to the United Kingdom′ s National Ecosystem Assessment. *Ecosystem Services* 5: 149-159.

Liu, J.L. and Wong, M.H. (2013). Pharmaceuticals and personal care products (PPCPs): a review on environmental contamination in China. *Environment International* 59: 208-224.

Love, D.C., Halden, R.U., Davis, M.F. and Nachman, K.E. (2012). Feather Meal: A Previously Unrecognized Route for Reentry into the Food Supply of Multiple Pharmaceuticals and Personal Care Products (PPCPs). *Environmental Science & Technology* 46(7): 3795-3802.

Morgan, M.G. and Henrion, M. (1990). Uncertainty: a Guide to dealing with uncertainty in quantitative risk and policy analysis Cambridge University Press.

Nakada, N., Shinohara, H., Murata, A., et al. (2007). Removal of selected pharmaceuticals and personal care products (PPCPs) and endocrine-disrupting chemicals (EDCs) during sand filtration and ozonation at a municipal sewage treatment plant. *Water Research* 41(19): 4373-4382.

Pieters, J.J., Verhaak, C.M., Braat, D.D., van Leeuwen, E. and Smits, A.P. (2012). Experts' opinions on the benefit of an incidental prenatal diagnosis of sex chromosomal aneuploidy: a qualitative interview survey. *Prenat Diagn* 32(12): 1151-1157.

Pingali, P. (2007). Westernization of Asian diets and the transformation of food systems: implications for research and policy. *Food Policy* 32(3): 281-298.

QSR (2012). NVivo qualitative data analysis software, QSR International Pty Ltd.

Rosi-Marshall, E. and Royer, T. (2012). Pharmaceutical Compounds and Ecosystem Function: An Emerging Research Challenge for Aquatic Ecologists. *Ecosystems* 15(6): 867-880.

Rosi-Marshall, E.J., Snow, D., Bartelt-Hunt, S.L., Paspalof, A. and Tank, J.L. (2015). A review of ecological effects and environmental fate of illicit drugs in aquatic ecosystems. *Journal of Hazardous Materials* 282(0): 18-25.

Rudd, M., Ankley, G., Boxall, A. and Brooks, B. (2014). International scientists' priorities for research on pharmaceutical and personal care products in the environment. *Integrated environmental assessment and management* 10(4): 576-587.

Rudd, M.A. (2015). Scientists' framing of the ocean science–policy interface. *Global Environmental Change* 33(0): 44-60.

Santos, L.H.M.L.M., Araujo, A.N., Fachini, A., et al. (2010). Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. *Journal of Hazardous Materials* 175(1-3): 45-95.

Serger, S.S., Benner, M. and Liu, L. (2015). Chinese university governance: Tensions and reforms. *Science and Public Policy*.

Shaw, L., Phung, C. and Grace, M. (2015). Pharmaceuticals and personal care products alter growth and function in lentic biofilms. *Environmental Chemistry* 12(3): 301-306.

Soon, J.M., Davies, W.P., Chadd, S.A. and Baines, R.N. (2012). A Delphi-based approach to developing and validating a farm food safety risk assessment tool by experts. *Expert Systems with Applications* 39(9): 8325-8336.

Stern, P. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of social issues* 56(3): 407-424.

Thach, A.V., Brown, C.M. and Pope, N. (2013). Consumer perceptions about a community pharmacy-based medication take back program. *Journal of Environmental Management* 127: 23-27.

Tong, A.Y., Peake, B.M. and Braund, R. (2011). Disposal practices for unused medications around the world. *Environment International* 37(1): 292-298.

Wang, J., He, B. and Hu, X. (2015). Human-use antibacterial residues in the natural environment of China: implication for ecopharmacovigilance. *Environmental Monitoring and Assessment* 187(6): 1-14.

Wang, M., Webber, M., Finlayson, B. and Barnett, J. (2008). Rural industries and water pollution in China. *Journal of Environmental Management* 86(4): 648-659.

Williams, E.S. and Brooks, B. (2012). Human Health Risk Assessment for Pharmaceuticals in the Environment: Existing Practice, Uncertainty, and Future Directions. *Human Pharmaceuticals in the Environment*. Brooks, B.W. and D.B. Huggett, Springer New York. 4**:** 167-224.

Xi, B., Li, X., Gao, J., et al. (2015). Review of challenges and strategies for balanced urban-rural environmental protection in China. *Frontiers of Environmental Science & Engineering* 9(3): 371-384.

Zhang, Q.Q., Ying, G.G., Pan, C.G., Liu, Y.S. and Zhao, J.L. (2015). Comprehensive Evaluation of Antibiotics Emission and Fate in the River Basins of China: Source Analysis, Multimedia Modeling, and Linkage to Bacterial Resistance. *Environmental Science & Technology* 49(11): 6772-6782.

Zhou, L.-J., Ying, G.-G., Liu, S., et al. (2013). Occurrence and fate of eleven classes of antibiotics in two typical wastewater treatment plants in South China. *Science of the Total Environment* 452: 365-376.

CHAPTER FOUR

Behavior, preferences and willingness to pay for measures aimed at preventing pollution by pharmaceuticals and personal care products in China

Xiaowen Wang[†], Peter Howley[†], Alistair B.A. Boxall[†], Murray A. Rudd[††*]

† Environment Department, University of York, Heslington, York, United Kingdom

†† Department of Environmental Sciences, Emory University, United States

* To whom correspondence may be addressed

Dr. Murray Rudd
Department of Environment Sciences
Emory University
Atlanta, Georgia
30322
USA
Email: murray.a.rudd@emory.edu; murrayrudd@hotmail.com
Tel: 404-727-3262; Fax: 404-727-4216

Abstract

The release of pharmaceuticals and personal care products (PPCPs) into the environment has been held up as a potential threat to ecosystem and human health. Using a custom designed survey of residents living in Xiamen China, this paper examines individuals' disposal practices, awareness of the environmental impact of PPCPs, and willingness to pay for measures aimed at reducing the likelihood of PPCPs being released into the environment. The vast majority of respondents report that they dispose of PPCPs through the thrash. The results of a contingent valuation experiment suggest a substantial willingness to pay (WTP) for policy measures aimed at reducing PPCP pollution. Income as well as subjective perceptions relating to overall financial health, expenditure on PPCPs and overall concern with environmental issues emerged as significant predictors of respondents' WTP. Our results should be of interest to policymakers looking for ways to mitigate the introduction of PPCPs in the environment.

Keywords: Contaminants; CVM; disposal practices; nonmarket valuation; stated preferences

Introduction

The introduction of bioactive chemicals from pharmaceuticals and active ingredients in personal care products (hereafter 'PPCPs') may pose a threat to ecosystem and human health (Daughton and Ternes 1999; Bound and Voulvoulis 2005; Santos et al. 2007; Rosi-Marshall and Royer 2012; Ferguson et al. 2013). With advances in monitoring and detection, scientists have established PPCPs as pervasive pollutants in water bodies (Sacher et al. 2001; Kolpin et al. 2002; Ternes et al. 2004; Weigel et al. 2004; Roberts and Thomas 2006). While the full effects of PPCPs are not yet fully understood (Fent et al. 2006; Girardi et al. 2011; Narvaez and Jimenez 2012) and the links between PPCPs in the environment and the final ecosystem services that matter to people are not well defined (Huerta et al. 2013), concern is growing about the implications of PPCPs in the environment (Narvaez and Jimenez 2012) and the topic has been identified as an important international research priority (Boxall et al. 2012; Rudd et al. 2014).

The human excretion of PPCPs into wastewater is the primary mechanism by which PPCPs are introduced into the environment (Fent et al. 2006). Our bodies absorb only a fraction of the medication that we swallow; most of the reminder is excreted and thereby ultimately is disposed of in wastewater (Daughton and Ternes 1999). PPCP products may remain un-degraded during the sewage treatment process and be discharged into waterways after treatment or be bound with solid waste. They may also be released to the environment by improper disposal of unused and expired PPCPs in household garbage or wastewater (Ruhoy and Daughton 2007; Comeau et al. 2008).

The limited evidence that is available suggests that the most common method for disposal is through garbage disposal, followed by flushing unused medication down the toilet or sink (COMPAS 2002; Abahussain et al. 2006; Seehusen and Edwards 2006; Kruopienė and Dvarionienė 2007; Kotchen et al. 2009; Tong et al. 2011), but this varies regionally. For example, in a survey of 1000 Swedish citizens, Persson et al. (2009) found that 55% of respondents saved unused drugs and 43% stated that they returned them to a pharmacy; only 3% reported that they threw out drugs with household garbage. The group that reported that they would leave the drugs in the cupboard were probed further to ascertain what they would do when the 'drugs definitely cannot be used anymore and you want to get rid of it'. Fifty five percent of the sample reported that they would then return them to a pharmacy. In Canada, over a 12 months' period, 50% of people surveyed had disposed of drugs in the garbage and 19% had disposed of them via the toilet or sink (COMPAS 2002). In a more recent USA survey (Kotchen et al. 2009), 43% of respondents stated that they were aware that pharmaceuticals have been detected in the environment; those who were aware were more likely, in turn, to return unwanted medications to pharmacies. Nonetheless, the majority of respondents – both those who were aware that pharmaceuticals were found in the environment and those who were not – disposed of their unused medications by throwing them in the trash (45% of total sample) or down the toilet/sink (28% of total sample). A similar disposal pattern was noted in a survey of UK residents (Bound and Voulvoulis 2005), where 66% of respondents reported that they discarded unwanted pharmaceuticals in household waste and a further 12% flushed them down the sink or toilet; the remaining 22% returned unwanted pharmaceuticals to a pharmacy. In Kuwait, Abahussain et al. (2006) found that 77% of survey respondents disposed of unused drugs via household garbage and a further 11% flushed them down the drain. (see supplemental data S4 in Appendices)

To the best of our knowledge, no studies on the disposal of PPCPs have been conducted in developing economies. In populous countries like China, India, Brazil, Indonesia and others, economies are growing rapidly and it is reasonable to expect that potential adverse effects of PPCPs in the environment is relatively high because of the combination of large populations, the availability of many pharmaceuticals without prescriptions, low levels of citizens' awareness of the potentially adverse effects of PPCPs in the environment, inadequate options for disposing of expired PPCPs, and relatively ineffective wastewater and solid waste treatment. There are a number of different options to reduce the likelihood of PPCPs being released into the environment. Interventions could target a series of sectors, such as: the health care industry (e.g., eco-pharmacovigilance – getting doctors to prescribe more accurately), the farming industry (e.g., to get the farms to use veterinary drugs more cautiously), the consumers of PPCP products (e.g., educational programs aimed at introducing safe disposal practices), the agents of PPCP products (e.g., educational programs taken at local pharmacies for customers) and the governments or companies responsible for the treatment of solid waste and wastewater (e.g., to invest in treatment technologies that could safely remove PPCPs from waste streams) (Seehusen and Edwards 2006; Kleywegt 2007; Gagnon et al. 2008; Wang and Hu 2014). Those measures are likely to vary greatly in cost, so cost-benefit analysis will be important.

Our study takes a step in this direction. We examine Chinese citizens' current behavior in relation to the disposal of unused PPCPs as well as their willingness to pay for measures aimed at reducing the impact of PPCP pollution in Xiamen, a large coastal city (population = 3.5 million) in southern China. PPCPs have been detected in both ground and surface waters in China (Sui et al. 2010; Peng et al. 2012; Liu and Wong 2013; Sun et al. 2014; Wang et al. 2014), highlighting that PPCPs in the aquatic environment is a potentially important issue nationally. Our survey asked respondents from 605 household about their general awareness of PPCP contamination and disposal practices, and their willingness to participate in a hypothetical voluntary disposal program established at a local pharmacy for safe disposal of PPCPs. We also used a contingent valuation scenario in the survey to estimate how much the general public would be willing to pay for measures aimed at preventing PPCP contamination in Xiamen. To date only Kotchen et al. (2009), who examined Californian residents' willingness to pay for a disposal program implemented at a local pharmacy, has assessed the economic benefits of controlling PPCP release into the environment. Our results should be of interest to policymakers looking for ways to mitigate the introduction of PPCPs in the environment and for researchers in other developing countries who are seeking to conduct increasingly detailed cost-benefit or cost-effectiveness analysis of environmental management issues that involve contaminants in the environment.

Methods

To answer our research questions required that we asked a variety of different types of questions directly of households in Xiamen. The format of the questions relating to demographic variables, household expenditure on PPCPs, and disposal practices were straightforward, following established formats used elsewhere (e.g. Kotchen et al. (2009); Persson et al. (2009); Tong et al. (2011)). To estimate marginal willingness to pay for changes in PPCP disposal options was, however, more complex because the question is hypothetical in nature. We thus used contingent valuation methodology (CVM) (Mitchell and Carson, 1989) to address our research question about the potential economic benefits that accrue to households due to reduced releases of PPCPs to the aquatic environment in Xiamen.

Sample frame

Xiamen has experienced rapid economic development and now contains six districts. Huli and Siming comprise what is known as the old urban island, an area with a population density of >13000 people per km^2 (higher than Hong Kong and Singapore). The four other districts, Haicang, Jimei, Tong'an and Xiang'an, are connected with mainland China. They are less urban in nature, with a variety of farms, but still with a substantial human population (see supplemental data S5 in Appendices).

A variety of household level sampling for different Chinese projects has taken place recently in Xiamen. Researchers from the Institute of Urban Environment (IUE) of the Chinese Academy of Sciences (CAS) in Xiamen developed a stratified random sampling method for the city (Gao et al. 2010). The GIS-based framework was based on a sandwich spatial sampling approach (Wang et al. 2012). Working with the CAS, we were able to utilize their sampling framework to formulate a sampling plan for this survey. We first deemed the 'neighborhood committees' of Xiamen as the first stratification and, following Gao et al. (2010), chose relevant neighborhood committees from this stratification. Neighborhood committees are the lowest level of governance in China and play an important role in the daily life of Chinese. The population of a typical neighborhood committee of a city like Xiamen is more than 5,000. The administration team of a neighborhood committee is elected by the local residents, and consists of one director, one vice director, and three to seven members. The roles of the committees are in charge of civil affairs, such as arranging entertainment activities for the residents living in the committees, carrying out the national population census, monitoring the birth planning conditions, intermediating the neighbor disputations, and helping maintain social security. The use of gatekeeper neighborhood committees for introductions gave our team network access through which we could obtain survey responses. We then identified representative residents of each selected neighborhood committee as the sample respondents. The representative residents were those individuals who live in the neighborhood and usually attend neighborhood committee meetings. As such, this was not a random sampling method but was the closest alternative sampling method which we could feasibly implement given the need to abide by social norms in the area. Our approach reflected the difficulty in conducting a survey in China as it would not have been possible to conduct a random sample whereby interviewers select households themselves to survey. The only real possibility for collecting a survey in this area was to elicit help from neighborhood committees who would then invite residents to take part.

In Xiamen there are 476 neighborhood committees, including 321 in Huli and Siming, the urban island, and 155 in the remaining 4 districts. Based on the CAS sampling framework, we selected 28 neighborhood committees from which to draw interviewees. Of these, 18 were located in Huli and Siming, with the remaining 10 distributed across Haicang, Jimei, Tong'an and Xiang'an. There are special challenges to be faced when conducting household surveys in China; one cannot simply walk through a neighborhood and knock, for example, on the door of every 14th house. In our survey, we drew on cooperation from Chinese neighborhood committees in Xiamen to implement our sampling strategy. Two alternatives existed for contacting potential respondents. First, the director of a neighborhood committee could help gather together representatives of the residents of the committee and let them fill out the survey in a centralized location. Second, the director of a neighborhood committee could guide our interviewers to knock the doors of each representative of the residents when they could not be gathered together and provided instructions to the respondents individually. As both of the two methods were based on invitations of representative residents from the neighborhood committees and involved respondents filling out the same questionnaire, we deemed them as the same sampling method.

Given budget constraints, our aim was to distribute a total of 800 questionnaires among the 28 neighborhoods. Twelve field teams, consisting of 46 students enrolled in the Department of Biological Engineering of Jimei University, were formed to conduct the interviews with selected respondents. Students conducting the surveys were trained in interviewing techniques before the data collection phase. During the survey, each team was in charge of two or three neighborhood committees. Before the interview, the leader of each team described the aims of the survey as well as the interview protocols to the director of the targeted neighborhood committee. On the day of the interviews, the members of each team went to the targeted neighborhood committees (one day for one neighborhood committee) and took the interviews with the help of the director of the neighborhood committee. After the interview, the leader of each interview team went back to the IUE and submitted the questionnaires.

Survey instrument

The survey questionnaire collected information related to households' use and disposal of PPCPs, their knowledge relating to the effect of PPCPs, and their willingness to take part in a voluntary disposal program implemented at local pharmacies. First, respondents were asked how many different personal care products they used daily and how many different pharmaceuticals they used during the past 4 weeks. They were also asked how much, on average, they spent each month on PPCPs. Next we asked respondents how they typically disposed of unwanted PPCPs and also how likely it is that they would return unused PPCPs for safe disposal at a pharmacy if a disposal program were implemented. Finally we asked respondents to indicate if they were aware that compounds from pharmaceuticals and personal care products can have a negative effect on the environment.

The final part of the survey questionnaire consisted of a CVM scenario designed to assess respondents' willingness to pay for measures aimed at preventing PPCPs from being released into the environment. CVM is a 'stated preference' valuation method that is based on survey and commonly used to estimate the value of non-market environmental resources or for eliciting preferences for hypothetical scenarios that would generate a change in individual well-being (Mitchell and Carson 1989). A CVM survey most often directly asks respondents how much they are willing to pay for a good or service that improves their wellbeing. The three primary elicitation formats in the CVM literature are open-ended, payment cards and dichotomous choice, each with their own advantages and disadvantages (Boyle 2003). The payment card method which was first developed by Mitchell and Carson (1989) was used in this study, as it does not require large samples. An additional advantage of the payment card approach is that it avoids the 'anchoring' effects of dichotomous choice formats, since respondents select their own willingness to pay or willingness to accept amount.

Often CV practitioners scrutinize respondents reasons for not being willing to pay and exclude those who they identify as providing what they deem as a 'protest response'. In this study, we adopted a cautious approach by not excluding any zero bids irrespective of the reasons given for not being willing to pay. This was to ensure representativeness of the survey dataset but will perhaps have the effect of placing a downward bias on our

WTP estimates which should at least partly mitigate the effect of any potential hypothetical bias.

In order to assess individuals' WTP for measures aimed at preventing pollution by PPCPs we presented respondents with some information describing the potentially harmful effects of PPCPs on the environment. We also described two potential options for reducing PPCP pollution that would need extra funding to help finance it. These were equipping sewage treatment plants with filters to separate the PPCPs and also biological treatment. The second is a nationwide drop-off program where residents could return unused PPCPs to be disposed of in a secure and environmentally sound manner (see supplemental data S1 in Appendices for a more detailed description of the background information given to respondents). Respondents were then presented with a payment card and asked what would be the maximum annual fee that they would be willing to pay to support measures aimed at preventing PPCPs from being released into the environment.

Data Analysis

When determining the influences on the willingness to pay of the individuals for policy measures aimed at reducing the release of PPCPs into the environment, we must first address a challenge in econometric analysis. A small number of observations are right censored at 450 yuan ($73) (see supplemental data S2 in Appendices), for whom the only thing we understand is that they would be willing to pay more than 450 yuan. As willingness to pay can only take zero or positive value, it is also left censored at 0. By considering the censored status of the collected data, we established a Tobit model of WTP, which can be represented as:

$$y_i^* = \beta' x_i + \varepsilon_i \tag{4.1}$$

Here, yi* represents the dependent variable (individuals WTP) which is latent and unobservable; x represents the independent variables which is a vector and can impact WTP; β represents the parameters which is a vector; and ε_i represents the error term with the independent and normal distribution. The forecasted yi* can be any values and not restricted to the censoring mechanism. The censoring points are 0 and 450 yuan, so we only know the value of yi* lower or equal to 450 yuan. We use maximum likelihood estimation (MLE) method to obtain the estimates from the Tobit model. The likelihood function of MLE can be divided into two parts. The first part aims to get the parameter estimates by using all of the observations, which can forecast an observation is censored or uncensored precisely. The second part aims to get the parameter estimates by only using the observations located in (0, 450) (i.e. uncensored observations), which forecasted values are closest to the observed values. In the Tobit model, the final parameter estimates are the common set which can maximize the two parts of the likelihood function simultaneously (Long 1997). We tested for multicollinearity between model variables using a tolerance test and variance inflation factors (VIF).

Results and discussion

We distributed 800 questionnaires, of which 718 questionnaires were returned (638 from the urban island and 80 from the rural mainland districts). After review, we deleted from the dataset those respondents who (1) did not answer the questions about annual personal income and (2) willingness to pay for reductions of PPCPs in the environment. That left us with 605 usable responses.

Respondents' preferences for uses and expenditures of PPCPs

Most respondents report that they use personal care products daily: 49 respondents (8.4% of the sample) used three or more products daily; 241 (41.3%) used two products daily; 112 (41.3%) used one product daily; and only 85 (14.6%) reported they used no personal care products. Almost half of respondents had used pharmaceutical products over the past four weeks: 21 respondents (3.6% of the sample) used four or more medicines over the last four weeks; 70 (11.9%) used three or four pharmaceutical products; 96 (16.3%) used two pharmaceutical products; 118 (20.0%) used one pharmaceutical product; and 285 (48.3%) reported they used no pharmaceutical products over the past four weeks. Table 4.1 shows mean respondent spending on PPCPs.

Respondents' preferences for disposal of PPCPs

For personal care products, 396 respondents (65.9% of the sample) discarded products in the trash, 165 (27.5%) threw them away after packing, 15 (2.5%) flushed them down the toilet, 9 (1.5%) used them until finished, 4 (0.7%) resold the personal care products to others, and 12 (2.0%) disposed of them in other ways. Proportions were similar for pharmaceutical products: 385 respondents (64.1% of the sample) discarded products in the trash; 179 (29.8%) threw them away after packing; 18 (3.0%) flushed them down the toilet; 5 (0.8%) used them until finished; 3 (0.5%) resold the pharmaceutical products to others; and 11 (1.8%) disposed of them in other ways. While the most common reported means of disposal in the international literature has been by discarding them in the trash (Tong et al. 2011), the extent of this practice among our respondents seems to be much greater than in other regions (e.g., 63% and 45% of respondents in UK and US surveys, respectively – see Bound and Voulvoulis 2005, and Kotchen et al. 2009).

Table 4. 1 - Expenditures per month (yuan) on personal care products and pharmaceuticals

Spending (yuan $month^{-1}$)	Personal care products		Pharmaceuticals	
	n	Percent	n	Percent
0 to 50	198	33.4	261	43.94
50 to 100	148	25.0	137	23.06
100 to 150	80	13.5	65	10.94
150 to 200	62	10.5	43	7.24
200 to 300	62	10.5	49	8.25
300 to 400	20	3.4	18	3.03
400 to 500	16	2.7	15	2.53
>500	7	1.2	6	1.01

Table 4. 2 – Factors affecting willingness to take part in a disposal program

Variables	Coef.	Std. Err.	P>z
Age under 30	0.01	0.28	0.98
Age between 30 and 50*	0.44	0.24	0.07
Female	0.17	0.18	0.33
Third level education*	0.42	0.22	0.06
High school education**	0.72	0.23	0.00
Dependent children**	-0.51	0.22	0.02
Middle income	-0.01	0.20	0.95
High income	-0.10	0.30	0.73
Reported very good health status**	0.56	0.26	0.03
Reported good health status*	0.36	0.19	0.06
Expenditure on personal care products	0.00	0.00	0.12
Expenditure on pharmaceuticals	0.00	0.00	0.81
Awareness of the effects of PPCPs***	0.47	0.18	0.01

* Indicates statistically significant at 10% level, **statistically significant at 5% level, *** statistically significant at 1% level

Next respondents were asked how likely/unlikely it is that they would return unused medicines or personal care products for safe disposal at a local pharmacy if a disposal program were implemented. While only 120 respondents (20.0%) reported that they would be very likely to return unused PPCPs to a pharmacy, 274 respondents (45.7%) were somewhat likely to participate in a disposal program. Other responses included: 72 (12.0%) neither likely nor unlikely; 55 (9.2%) unlikely; and 78 (13.0%) very unlikely to participate in a disposal program. We next formulated an ordered logit regression model to examine what factors are associated with respondents stated willingness to participate (Table 4.2) (see supplemental data S3 in Appendices for a description of all variables used in the regression analysis).

Our analysis indicated that education is significantly and positively related with the probability of respondents reporting that they would return unwanted PPCPs. Specifically respondents with a third level or high school education were significantly more likely to report that they would participate in a voluntary disposal program than individuals with a primary or middle-school education. Age appeared to be non-linearly related with willingness to participate as individuals between the ages of 30 and 50 yrs were more likely to participate in a disposal program than individuals < 30 and > 50 yrs, respectively. Respondents with dependent children were significantly less likely to report that they would participate in a voluntary disposal program. One potential hypothesis to explain this finding is that this variable reflects time constraints in that this cohort may find it more difficult to return unwanted PPCPs than other groups (e.g., individuals without children). On the other hand, respondents with a higher self-reported health status were significantly more likely to report that they would return unused PPCPs. Similar to the finding relating to the effect of having dependent children, this may also be explained by differences in the ability or ease with which respondents with different levels of health could return unwanted PPCPs. Some 61% of respondents reported that they were aware that compounds from medicines and personal care products can have a negative effect on the environment. Those individuals who reported that they were aware of this negative environmental impact were more likely to state that they would return unused PPCPs to a pharmacy if a disposal program was implemented.

Willingness to pay for measures aimed at reducing the release of PPCPs

The regression results from our Tobit model of willingness to pay (WTP) are presented in Table 4.3. A tolerance test and associated variance inflation factors (VIF) showed no evidence for multicollinearity between any of the model variables (tolerance ranged between 0.44 and 0.93, mean VIF 1.60). The overall mean bid amount was estimated at 71 yuan (approximately US $11.65) person^{-1} year^{-1}. A total of 246 individuals (40.7% of the sample) were unwilling to pay anything towards the cost of various measures aimed at reducing levels of PPCPs in the environment. Some of those respondents may feel that they can’t afford to pay or they simply may do not value the good being offered. On the other hand, respondents might also hold other beliefs that protest some aspect of the valuation process and their reasons for not paying may include an objection towards the proposed means of bringing about the change in the public good (e.g. the payment vehicle), an ethical objection to the idea of placing valued environmental objects in a market context or a belief that paying for environmental quality is the responsibility of government rather than individual citizens (Jorgensen and Syme 2000).

Based on a population of approximately 3 million adults living in Xiamen, our results would imply an annual benefit of 218 m yuan (US $36 m) for policy measures aimed at reducing PPCP pollution in the aquatic environment. Extrapolation to other parts of the country would be biased because WTP would certainly differ in other parts of the country given the heterogeneous nature of households in China. That said, the results presented here would certainly be suggestive of significant net benefits from implementing measures to limit the release of PPCPs into the environment.

As with any stated preference study, these results should be interpreted with some caution given the widely reported tendency for respondents to overstate their WTP for environmental issues due to a desire to ‘look good’ (Lusk and Norwood 2010). List and Gallet (2001) and Murphy et al. (2003) both conducted meta-analyses of the experimental bias literature with both indicating that mean hypothetical values are about 2.5 to 3 times greater than non-hypothetical values, but that this comes from a highly skewed distribution with a median ratio closer to 1.5 times non-hypothetical values. In this study, we adopted a cautious approach by not excluding any potential protest responses (i.e., all zero bids irrespective of the reasons given for not being willing to pay were included).

This was to ensure the representativeness of the survey dataset but will also perhaps have the effect of placing a downward bias on our WTP estimates. This, in turn, should at least partly mitigate the effect of any potential hypothetical bias.

Table 4. 3 – Factors affecting willingness to pay for reducing PPCPs in the aquatic environment in Xiamen, China (n=503)

Variables	Coef.	Std. Err.	P>t
Age under 30	22.73	24.10	0.35
Age between 30 and 50	1.87	21.78	0.93
Third level education	-29.55	18.97	0.12
High school education	-17.46	19.70	0.38
Dependent children	-14.82	19.13	0.44
Female	9.97	15.54	0.52
Middle income*	30.10	17.96	0.09
High income**	56.83	26.11	0.03
Financial status very or fairly good**	40.62	18.61	0.03
Financial status neither good nor bad*	37.82	20.64	0.07
Expenditure on personal care products***	0.21	0.07	0.01
Expenditure on pharmaceuticals***	0.20	0.07	0.01
Very concerned about the environment in general***	58.96	23.47	0.01
Fairly concerned about the environment in general**	44.35	22.73	0.05
Likelihood ratio chi-square (14)***	48.37		
N = 503 households 219 left censored observation at WTP <= 0 279 uncensored observations 5 right censored observations at WTP > 450			

* Indicates statistically significant at 10% level, **statistically significant at 5% level, *** statistically significant at 1% level

Table 4.3 suggests that there is very little variability in WTP across demographic groupings. For example, age, education, gender and the presence of dependent children were not significantly related with WTP. Income was, however, found to have a significant relationship with WTP as respondents earning above 48,000 yuan ($7,800 which we label as high income) willing to pay an average of 57 yuan per annum more than individuals earning less than 14,400 yuan ($2,300). Respondents earning between 14,400 and 48,000 (labelled as middle income) were willing to pay an average of 41 yuan more on average than individuals earning less than 14,400 yuan.

We also found that respondents' own subjective evaluation of the financial status of their household was an important predictor of WTP. To ascertain respondents' subjective evaluation of the adequacy of their income, they were asked in the survey to indicate how they rate the financial situation of their household (from very good to very bad on a 5-level Likert scale). We used this information to create two dummy variables representing respondents who rated their financial situation as either very good or good. Respondents who rated the financial situation of their household as either very good or good were willing to pay an average of 41 and 38 yuan, respectively, more than respondents who rated the financial situation of their household as less than good.

The respondents' perceptions of financial status are important mainly for the following two reasons: one, due to the differences in cost of living across regions and respondents' debt levels, perceptions of financial status may be a more accurate measure of purchasing power; the other, individuals' perceptions toward certain circumstances may be as important as the reality of those circumstances themselves. The real income levels of respondents could be relatively low but they might recognize themselves as being relatively high wealthy and vice-versa. To illustrate this, we examined the strength of the relationship between actual income levels and subjective evaluations by running a bivariate correlation between our income variable and respondent's perceptions of financial health. The estimated correlation coefficient at 0.15, while statistically significant, was weak suggesting that a variety of other factors in addition to actual income levels affect perceptions of financial status. It would be useful for further work in the non-market valuation sphere to determine if perceptions of financial health emerge as a more significant and relevant predictor of WTP for other environmental goods and services, than objective measures of income.

Expenditure on both pharmaceuticals and personal care products were both positively related with WTP. This could reflect a greater sense of responsibility to reduce the effect of PPCP pollution felt by those most likely to cause this type of pollution. Finally, respondents who reported that they were very concerned or fairly concerned about the environment were willing to pay an average of 59 and 44 yuan more, respectively, than respondents who report that they are not concerned with environmental issues.

Study limitations

One important point to note is that the sample area is restricted to a city in China (Xiamen). It is a coastal city with relatively high economic development and a large population. Residents in other areas of China may have different disposal practices and WTP for measures aimed at reducing the environmental effects from PPCP pollution. In addition, given the inherent difficulties of conducting surveys in China, we relied on using neighborhood committees to assist us in targeting respondents to survey. The individuals invited to take part in the survey by the neighborhood committee may have different views towards issues surrounding PPCP pollution than the wider population at large. Unfortunately this is something we cannot rule out and it would be useful for future work to survey residents living in other regions in China. Despite this note of caution, the analysis of this survey dataset does give us a good initial understanding of the disposal practices of Chinese citizens, their willingness to partake in a voluntary disposal program, and, finally, willingness to pay for policy measures aimed at reducing PPCP pollution.

Conclusion

During the last four decades the effect of conventional ‘priority’ pollutants (e.g., acutely toxic pesticides, industrial contaminants) on the environment has been the subject of much scientific research. In more recent times, the effect of pharmaceuticals and bioactive ingredients in personal care products has been identified as a growing environmental concern (Daughton and Ternes 1999; Bound and Voulvoulis 2005; Boxall et al. 2012). If the likely environmental impact of PPCPs is to be reduced, then we need research to better understand household disposal practices and also how much individuals are willing to pay for policy measures aimed at preventing PPCP pollution. In this study, we conducted a survey of residents in Xiamen, China, to examine awareness of PPCP pollution, use of PPCPs, disposal practices, willingness to participate in a disposal program at a local pharmacy and willingness to pay for measures to reduce the effect of PPCPs in the aquatic environment. This is the first such study that we are aware of in China; due to its population size and growing use of PPCPs, disposal practices in China may have a significant impact on the global environment.

Respondents were asked to report their typical method for disposing of pharmaceuticals and personal care products. In line with the existing international literature, we found that disposal of unwanted PPCPs in the trash is the most common disposal method. The proportion of households disposing of PPCPs in the trash either alone or packed with other household waste (approximately 93%) is the highest reported percentage in the literature to date (see Tong et al., 2011 for a review of this literature). It appears, therefore, that there is substantial scope to reduce PPCP pollution through changing household disposal practices. It is encouraging to note that the majority of respondents in our survey are aware that PPCPs have been detected in the environment and also can have a negative environmental impact. This perhaps reflects the increasing attention being given to this issue in China (Bu et al. 2013). For example, some cities (e.g., Dalian) have adopted pharmaceutical recycling programs, and the Chinese government also has begun to pay more attention towards monitoring the levels of PPCPs in the aquatic environment (Bu et al., 2013). Still there is a significant minority (40%) of respondents in China who reported that they were unaware of any harmful environmental effects.

We determined respondents' willingness to take part in a proposed hypothetical voluntary disposal program at a local pharmacy as this is likely to be one relatively cost-effective method for reducing the release of PPCPs into the environment. We found that awareness of the potential environmental effects of PPCPs was a significant predictor of respondents' willingness to take part in such a program. Consequently, further efforts aimed at increasing the knowledge base of citizens when it comes to this issue are likely to be an effective avenue towards reducing PPCP pollution through changing respondents' disposal practices. Further factors found to be related with willingness to participate include education, the presence of dependent children, and self-reported health status. We hypothesize that the latter two variables capture the ease with which respondents could return unwanted PPCPs if a disposal program at a local pharmacy was to be implemented.

The results of the contingent valuation approach indicate a substantial willingness to pay for policy measures aimed at reducing PPCP pollution. In future work, it would be useful to use this information to compare the economic benefits of policy measures aimed at reducing PPCP pollution with the economic costs involved. Beyond evidence on overall WTP, we find that certain groups of respondents have a higher WTP. For instance, we find a positive association between respondents' expenditure on PPCPs and their willingness to pay. This could be suggestive of a greater willingness on the part of these respondents to bear additional costs associated with mitigating their impact. This could perhaps be attributable to a greater sense of responsibility to reduce any negative environmental impact from PPCP use, felt on the part of respondents most likely to cause environmental damage through their use of PPCPs. Therefore, one potentially useful policy approach could be to implement a surcharge on the use of PPCPs that are likely to have a negative environmental impact. Such an approach would target the costs associated with mitigating the effect of PPCPs towards respondents who are responsible for their release. We also find both income as well as subjective perceptions relating to a households financial health to be important predictors of WTP. It would be useful in further work to examine if subjective evaluations of the adequacy of income emerge as a more relevant predictor of WTP than objective measures of income, when respondents are asked to value other environmental goods and services. Finally, as one would expect, WTP was positively related with general environmental concern.

Acknowledgements

We thank Shenghui Cui and Yong-Guan Zhu (Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen) for assistance with organizing the Xiamen survey. The authors declare that they have no conflicts of interest.

Supplementary Information

Supplemental data S1 – Contingent valuation survey scenario presented to respondents
Supplemental data S2 – Censored bid acceptance
Supplemental data S3 – Summary statistics of variables used in regression analysis
Supplemental data S4 – Summarization of the literature review on preferences around disposal of PPCPs
Supplemental data S5 – The reasons of choosing the city of Xiamen to take our survey research

References

Abahussain, E.A., Ball, D.E. and Matowe, W.C. (2006). Practice and opinion towards disposal of unused medication in Kuwait. *Medical Principles and Practice* 15(5): 352-357.

Bound, J.P. and Voulvoulis, N. (2005). Household disposal of pharmaceuticals as a pathway for aquatic contamination in the United Kingdom. *Environmental Health Perspectives* 113(12): 1705-1711.

Boxall, A., Rudd, M.A., Brooks, B.W., et al. (2012). Pharmaceuticals and personal care products in the environment: what are the big questions? *Environmental Health Perspectives* 120(9): 1221-1229.

Boyle, K.J. (2003). Contingent valuation in practice. *A primer on nonmarket valuation*, Springer**:** 111-169.

Bu, Q., Wang, B., Huang, J., Deng, S. and Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. *J Hazard Mater* 262: 189-211.

Comeau, F., Surette, C., Brun, G. and Losier, R. (2008). The occurrence of acidic drugs and caffeine in sewage effluents and receiving waters from three coastal watersheds in Atlantic Canada. *Science of the Total Environment* 396(2): 132-146.

COMPAS (2002). F&DA Environmental Assessment Regulations Project Benchmark Survey : a Report to Health Canada (POR-02-13), Office of Regulatory and International Affairs, The Office.

Daughton, C.G. and Ternes, T.A. (1999). Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives* 107: 907-938.

Fent, K., Weston, A.A. and Caminada, D. (2006). Ecotoxicology of human pharmaceuticals. *Aquatic Toxicology* 76(2): 122-159.

Ferguson, P.J., Bernot, M.J., Doll, J.C. and Lauer, T.E. (2013). Detection of pharmaceuticals and personal care products (PPCPs) in near-shore habitats of southern Lake Michigan. *Science of the Total Environment* 458: 187-196.

Gagnon, C., Lajeunesse, A., Cejka, P., Gagne, F. and Hausler, R. (2008). Degradation of Selected Acidic and Neutral Pharmaceutical Products in a Primary-Treated Wastewater by Disinfection Processes. *Ozone-science & Engineering*.

Gao, L., Li, X., Wang, C., et al. (2010). Survey Site Selection Based on the Spatial Sampling Theory: A Case Study in Xiamen Island [J]. *Journal of Geo-Information Science* 3: 009.

Girardi, C., Greve, J., Lamshoeft, M., et al. (2011). Biodegradation of ciprofloxacin in water and soil and its effects on the microbial communities. *Journal of Hazardous Materials* 198: 22-30.

Huerta, B., Marti, E., Gros, M., et al. (2013). Exploring the links between antibiotic occurrence, antibiotic resistance, and bacterial communities in water supply reservoirs. *Science of the Total Environment* 456: 161-170.

Jorgensen, B.S. and Syme, G.J. (2000). Protest responses and willingness to pay: attitude toward paying for stormwater pollution abatement. *Ecological Economics* 33(2): 251-265.

Kleywegt, S., Smyth, S.-A., Parrott, J., Schaefer, K., Lagacé, E., Payne, M., Topp, E., Beck, A., McLaughlin, A., and Ostapyk, K. (Editors). (2007). Pharmaceuticals and personal care products in the Canadian environment: research and policy directions. *Environment Canada, NWRI Scientific Assessment Report Series No. 8.*

Kolpin, D.W., Furlong, E.T., Meyer, M.T., et al. (2002). Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: A national reconnaissance. *Environmental Science & Technology* 36(6): 1202-1211.

Kotchen, M., Kallaos, J., Wheeler, K., Wong, C. and Zahller, M. (2009). Pharmaceuticals in wastewater: Behavior, preferences, and willingness to pay for a disposal program. *Journal of Environmental Management* 90(3): 1476-1482.

Kruopienė, J. and Dvarionienė, J. (2007). Pharmaceutical Pathways to the Environment in Lithuania. *Environmental Research, Engineering & Management* 41(3).

List, J.A. and Gallet, C.A. (2001). What experimental protocol influence disparities between actual and hypothetical stated values? *Environmental and Resource Economics* 20(3): 241-254.

Liu, J.L. and Wong, M.H. (2013). Pharmaceuticals and personal care products (PPCPs): a review on environmental contamination in China. *Environment International* 59: 208-224.

Long, J.S. (1997). Regression models for categorical and limited dependent variables. *Journal of the American Statistical Association* 17(13): 1534-1535.

Lusk, J.L. and Norwood, F.B. (2010). Direct versus indirect questioning: an application to the well-being of farm animals. *Social indicators research* 96(3): 551-565.

Mitchell, R.C. and Carson, R.T. (1989). Using surveys to value public goods : the contingent valuation method. Washington, D.C.
[Baltimore], Resources for the Future ;
Distributed worldwide by the Johns Hopkins University Press.

Murphy, F.C., Nimmo-Smith, I. and Lawrence, A.D. (2003). Functional neuroanatomy of emotions: a meta-analysis. *Cognitive, Affective, & Behavioral Neuroscience* 3(3): 207-233.

Narvaez, J.F.V. and Jimenez, C. (2012). PHARMACEUTICAL PRODUCTS IN THE ENVIRONMENT: SOURCES, EFFECTS AND RISKS. *Vitae-Revista De La Facultad De Quimica Farmaceutica* 19(1): 93-108.

Peng, X., Huang, Q., Zhang, K., et al. (2012). Distribution, behavior and fate of azole antifungals during mechanical, biological, and chemical treatments in sewage treatment plants in China. *Science of the Total Environment* 426: 311-317.

Persson, M., Sabelstrom, E. and Gunnarsson, B. (2009). Handling of unused prescription drugs - knowledge, behaviour and attitude among Swedish people. *Environment International* 35(5): 771-774.

Roberts, P.H. and Thomas, K.V. (2006). The occurrence of selected pharmaceuticals in wastewater effluent and surface waters of the lower Tyne catchment. *Science of the Total Environment* 356(1-3): 143-153.

Rosi-Marshall, E.J. and Royer, T.V. (2012). Pharmaceutical Compounds and Ecosystem Function: An Emerging Research Challenge for Aquatic Ecologists. *Ecosystems* 15(6): 867-880.

Rudd, M., Ankley, G., Boxall, A. and Brooks, B. (2014). International scientists' priorities for research on pharmaceutical and personal care products in the environment. *Integrated environmental assessment and management* 10(4): 576-587.

Ruhoy, I.S. and Daughton, C.G. (2007). Types and quantities of leftover drugs entering the environment via disposal to sewage - Revealed by coroner records. *Science of the Total Environment* 388(1-3): 137-148.

Sacher, F., Lange, F.T., Brauch, H.-J. and Blankenhorn, I. (2001). Pharmaceuticals in groundwaters: analytical methods and results of a monitoring program in Baden-Württemberg, Germany. *Journal of Chromatography A* 938(1): 199-210.

Santos, J.L., Aparicio, I. and Alonso, E. (2007). Occurrence and risk assessment of pharmaceutically active compounds in wastewater treatment plants. A case study: Seville city (Spain). *Environment International* 33(4): 596-601.

Seehusen, D.A. and Edwards, J. (2006). Patient practices and beliefs concerning disposal of medications. *The Journal of the American Board of Family Medicine* 19(6): 542-547.

Sui, Q., Huang, J., Deng, S., Yu, G. and Fan, Q. (2010). Occurrence and removal of pharmaceuticals, caffeine and DEET in wastewater treatment plants of Beijing, China. *Water Research* 44(2): 417-426.

Sun, Q., Lv, M., Hu, A., Yang, X. and Yu, C.-P. (2014). Seasonal variation in the occurrence and removal of pharmaceuticals and personal care products in a wastewater treatment plant in Xiamen, China. *Journal of Hazardous Materials* 277: 69-75.

Ternes, T.A., Herrmann, N., Bonerz, M., et al. (2004). A rapid method to measure the solid-water distribution coefficient (K-d) for pharmaceuticals and musk fragrances in sewage sludge. *Water Research* 38(19): 4075-4084.

Tong, A.Y., Peake, B.M. and Braund, R. (2011). Disposal practices for unused medications around the world. *Environment International* 37(1): 292-298.

Wang, D., Sui, Q., Lu, S.-G., et al. (2014). Occurrence and removal of six pharmaceuticals and personal care products in a wastewater treatment plant employing anaerobic/anoxic/aerobic and UV processes in Shanghai, China. *Environmental Science and Pollution Research* 21(6): 4276-4285.

Wang, J. and Hu, X. (2014). Ecopharmacovigilance: Current state, challenges, and opportunities in China. *Indian Journal of Pharmacology* 46(1): 13.

Wang, L., Ying, G.G., Chen, F., et al. (2012). Monitoring of selected estrogenic compounds and estrogenic activity in surface water and sediment of the Yellow River in China using combined chemical and biological tools. *Environmental Pollution* 165: 241-249.

Weigel, S., Berger, U., Jensen, E., et al. (2004). Determination of selected pharmaceuticals and caffeine in sewage and seawater from Tromsø/Norway with emphasis on ibuprofen and its metabolites. *Chemosphere* 56(6): 583-592.

CHAPTER FIVE

Conclusion

The main aim of this study was to examine the insights of Chinese public and experts into pharmaceuticals and personal care products (PPCPs) in the environment in China. To do this, I used a combination of environmental, social, and economic data that provided valuable information that could be useful in the development of policies and regulations to help minimize potential adverse effects of PPCPs in the Chinese environment.

Chapter two

From potential journal articles identified in an extensive literature search of 2982, I found a final selection of 60 relevant articles for a structured review. The average conclusion through these articles is that due to the scientific uncertainty, the real effects or risks of PPCPs in the environment on ecosystems and human health is still unknown or potential. While some of the chemical compounds of PPCPs in the aquatic or soil environment might pose risks to sensitive microorganisms or bring antibiotic resistance which levels are various through low to high influenced by seasons (dry or wet), human activities (like aquaculture activities near the coastal water), locations (like if receiving discharge wastewater) , etc.

Many of the sample sites of the reviewed studies were at or near the coastal area of China with large population and economic prosperity. The number of studies on the environment of western China was limited, which might imply that work on ecological risk assessment work should also be taken more evenly over the whole country. Besides supporting more scientific research in the west of China, I also discussed other policy options on regulating PPCPs in the environment in China, such as national draw-back program of unwanted or expired PPCPs, improving removal techniques of PPCPs in the wastewater treatment plants (WWTPs), and the possibility of taking pricing strategies by imposing higher taxes on manufactories producing high potential risk PPCPs. To test the feasibility of the four regulation options of PPCPs and conduct sufficient cost-benefit analysis, surveys facing experts, households, pharmacists, manufactories and WWTPs should be taken in the future studies.

Based on the results of my interviews, I suggest that most of the Chinese scientists interviewed shared similar opinions on numerous scientific or technical aspects issues regarding PPCPs in the environment in China. For example, nearly all of them tended to believe that antibiotic resistance selection by PPCPs in the environment could impose risks to human health, even though some of them considered current scientific evidence supporting this view as tentative. They also shared opinions that risks of PPCPs to wildlife were possible but yet to be demonstrated. Regarding the potential for effluent treatment methods to reduce PPCPs while not increasing toxicity levels of whole effluents, respondents mentioned more or less the same techniques and most of them stated that these were currently unreliable or prohibitively expensive given the current state of technology.

The respondents' ideas on management of PPCPs in the environment were more divergent. For example, their attitudes on communicating the risks of PPCPs to the public were not consistent, as some of them preferred to use the public media to build awareness of PPCPs among citizens, while others thought that accurate information needed to be handed to policy-makers and regulators. Based on our interview responses, and comparing them with the relevant international literature, we suggest that the following themes may be important to examine in more detail in China.

During our interviews with the Chinese scientists, we found that nearly half of them believed that scientific research and evidence on the effects of PPCPs in the Chinese environment are still limited and more experiments are thus needed before making any decisions on dealing with PPCPs in the environment. The Chinese scientists' attitudes on the scientific uncertainty and lack of scientific evidence of the specific effects or risks of PPCPs in the environment are in line with international perspectives (Williams and Brooks 2012; Arpin-Pont et al. 2014). Our respondents believed that, even though PPCPs are used nearly every day by everyone and could be deemed as a kind of persistent pollutant in the environment, that evidence of their potential risk was lacking. The issue of long-term chronic risk (and risk perception) is also important in other fields (Morgan and Henrion 1990; Krebs 2005).

Attitudes on whether the risks and effects of PPCPs in the environment are substantive may not only impact scientists' research priorities on the PPCPs in the environment, but also influence the government's opinions and actions on management and treatment of those PPCPs. The scientists who viewed PPCPs in the environment as trace pollutants that posed no verifiable risk to human health also thought traditional pollutants like metals were more severe in China, thereby requiring immediate solutions. While scientists and regulators in Western countries have adopted more precautionary approaches to environmental contaminants, the implicit view of Chinese scientists was more practically-oriented, with recognition of the relative importance of different kinds of contaminants in the environment and the economic implications of different approaches to control them.

Besides the difficulty of establishing criteria for policies and regulations to control and manage PPCPs in the environment, building awareness among the public of the effects and risks of PPCPs was viewed as a challenge. Effluent from municipal wastewater treatment plants, agricultural wastewater, and leaching of landfills to groundwater reservoirs are important sources of PPCPs in the environment (Liu and Wong 2013), and are closely related to human behavior. It may therefore be prudent to build awareness among the public about the potential risks and effects of PPCPs in the environment and engage them in efforts to help control PPCP release to wastewater and solid waste systems at the source. However, due to the scientific uncertainty (i.e., unclear links to human health), the fact that PPCPs occur at trace levels in the environment, and the daily necessity of (and lack substitutes for) many of the chemicals in PPCPs (Liu and Wong 2013), it may be difficult to explain to the public that their daily life could affect the environment and that the presence of these compounds in the environment might expose themselves to health risks in the future. Understanding how information provision, held worldview, core cultural values, and the perceived salience of environmental threats to well-being have been studied extensively in other fields (e.g., Stern (2000); Henry and Dietz (2012)). Given the potential importance of the Chinese consumer in designing interventions to curtail the release of PPCPs into the environment, there is a pressing need for future research that helps build understanding on the potential behavioral shifts and the effect of initiatives such as take back programs for expired pharmaceuticals in China.

The scientists we interviewed mentioned the power of the modern media – television programs, newspapers, radios and especially social media – to help communicate science. However, even though media can disseminate information about potential risks and effects of PPCPs in the environment to the public, there are still issues that need to be considered. First, scientists expressed concern about exaggerated reporting (sensationalism is apparently marketable in China as it is in the West). Some scientists were concerned that when, for example, news outlets reported that Beijing drinking water contained birth control pills, that citizens education and awareness of the true scientific concerns may be lost. From a theoretical perspective, encouraging pro-environmental behavior requires that people understand the threats or risks they might face if their behavioral intent is to change and, even then, other personal and institutional constraints can prevent individuals following through on their behavioral intent and actually taking action (Stern 2000). Second, scientists were concerned that uncertainty among Chinese citizens regarding the potential implications of PPCPs in the environment may affect the governments' willingness to take action. This implies that the scientists thought that there was a demand-side pull for policy and regulation rather than a policy supply-side push from governments taking a broader societal perspective on the public good. The relationship between academia and government has been changing rapidly in China (Serger et al. 2015) but it is generally viewed that only elite scientists have substantial influence on government science-based policy and regulatory decisions. That implies that rank and file scientists working on PPCPs in the environment may not have a realistic view of the science-policy interface process and highlights the potential importance in China, as it is in the West (Lawton and Rudd 2013), of senior and connected scientists in bridging the science-policy world.

The relationship between media-driven citizen complaints and the level of attention that different levels of government devote to those issues is unclear in China. Many times when the majority of the citizens realize that pollutants may be seriously affecting their health, it may be too late to efficiently control the problem. The level of awareness of environmental problems has increased greatly among Chinese citizens over the last decade (Xi et al. 2015) but some local governments (especially in rural and developing areas) still compromise environmental and human health for the sake of economic development. In many cases, corruption has played a role in poor water quality in rural areas and, even when regulations are in place and there is intent to enforce them, the scale of monitoring necessary to discourage pollution overwhelms government capacity to do so (e.g., Wang et al. (2008)).

Governments have multiple options for controlling PPCP release into the environment; they could set standards for PPCP waste discharge from factories and hospitals, regulate or encourage city families to recycle or dispose responsibly of unwanted PPCPs, more closely regulate the use of veterinary antibiotics in large farms, and impose restrictions on wastewater and solids disposal. To make effective and efficient choices, governments need evidence and engagement from scientific experts. In China, there are mechanisms for scientists to participate in providing policy-making advice, such as local and national Chinese People's Political Consultative Conference (CPPCC), and via the Chinese Academy of Science (CAS) and its affiliates. However, the process by which science reaches the policy world is not clear in the environmental contaminants realm as there is functionally no available information about the science-policy interface. There is a need to better understand how high-quality scientific evidence could support policy-makers and how various technical and managerial solutions and interventions may vary in effectiveness and cost.

In other realms of scientific research internationally, a variety of work has been done on scientists' willingness to engage with policy-makers and their views on their role at the science-policy interface. For example, in a global survey of ocean scientists, Rudd (2015) found three clusters of scientists who varied in their perspectives, the largest of which were evidence providers, who believed their job ends once scientific evidence is prepared and presented. In our interviews, all respondents could be classified as evidence providers. When scientists take on this role, it does mean that there must be important intermediaries at the science-policy interface in China, playing a role in identifying science perceived as important (for any of a variety of possible reasons) and translating it for government officials. Unfortunately, little is known about those policy entrepreneurs or the process by which they operate specifically in the environmental contaminants field in China. Evidence providers may also be less amenable to cross-disciplinary cooperation, instead focusing primarily on technical issues (Rudd 2015).

Currently much of the Chinese research on PPCP-related issues seems to largely focus on the occurrence, fate and effects of PPCPs in the environment and has focused on only a few PPCP classes such as antibiotics. While one respondent (R4) called for "cooperation with medical experts (as environmental scientists, we do not really familiar with medical science)", there appeared to be limited appreciation of need for transdisciplinary PPCP research (i.e., crossing disciplines and organization types). Wang et al. (2015) are, however, a noteworthy exception in this respect, calling for cross-disciplinary efforts to implement eco-pharmacovigilance initiatives in China. With China's strong focus on high-profile scientific advances and stratification of research institutions (Serger et al. 2015) in combination with an evidence provider orientation among scientists, the opportunities for cross-cutting environmental research may, however, be constraining.

A few local government and environmental organizations in China have taken actions on voluntary recycling of expired and unwanted pharmaceuticals, and government has been supportive of take-back programs (Wang et al. 2015). To help justify recycling initiatives, quantifying the monetary costs and benefits of different methods on controlling PPCP release into the environment will be necessary. Given the potential for PPCPs to have chronic effects on ecological structure and function, the costs and benefits of pollution and control measures on a spectrum of ecosystem services should be considered.

Chapter four

Respondents were asked to report their typical method for disposing of pharmaceuticals and personal care products. In line with the existing international literature, we found that disposal of unwanted PPCPs in the thrash is the most common disposal method. The proportion of households disposing of PPCPs in the thrash (+93%) is the highest reported percentage in the literature to date (see Tong et al. (2011)). It appears, therefore, that there is substantial scope to reduce PPCP pollution through changing household disposal practices. It is encouraging to note that the majority of respondents in our survey are aware that PPCPs have been detected in the environment and also can have a negative environmental impact. This perhaps reflects the increasing attention being given to this issue in China (Bu et al. 2013). For example, some cities (e.g., Dalian) have adopted pharmaceutical recycling programs, and the Chinese government also has begun to pay more attention towards monitoring the levels of PPCPs in the aquatic environment (Bu et al. 2013). Still there is a significant minority (40%) of respondents in Xiamen who reported that they were unaware of any harmful environmental effects.

We determined respondents' willingness to take part in a proposed hypothetical voluntary disposal program at a local pharmacy as this is likely to be one relatively cost-effective method for reducing the release of PPCPs into the environment. We found that awareness of the potential environmental effects of PPCPs was a significant predictor of respondents' willingness to take part in such a program. Consequently, further efforts aimed at increasing the knowledge base of citizens when it comes to this issue are likely to be an effective avenue towards reducing PPCP pollution through changing respondents' disposal practices. Further factors found to be related with willingness to participate include education, the presence of dependent children and self-reported health status. We hypothesize that the latter two variables capture the ease with which respondents could return unwanted PPCPs, if a disposal program at a local pharmacy was to be implemented.

The results of the contingent valuation approach indicate a substantial willingness to pay for policy measures aimed at reducing PPCP pollution (the overall mean bid amount was estimated at approximately US $11.65 per person per year). In future work, it would be useful to use this information to compare the economic benefits of policy measures aimed at reducing PPCP pollution with the economic costs involved. Beyond evidence on overall WTP, we find that certain groups of respondents have a higher WTP. Specifically, respondents who spend more on PPCPs are likely to be willing to pay relatively more. This could be suggestive of a greater willingness on the part of these respondents to bear additional costs associated with mitigating their impact. This could perhaps be attributable to a greater sense of responsibility to reduce any negative environmental impact from PPCP use, felt on the part of respondents most likely to cause environmental damage through their use of PPCPs. Therefore, one potentially useful policy approach could be to implement a surcharge on the use of PPCPs that are likely to have a negative environmental impact. Such an approach would target the costs associated with mitigating the effect of PPCPs towards respondents who are responsible for their release. We also find both income as well as subjective perceptions relating to a households financial health to be important predictors of WTP. It would be useful in further work to examine if subjective evaluations of the adequacy of income emerge as a more relevant predictor of WTP than objective measures of income, when respondents are asked to value other environmental goods and services. Finally, as one would expect, WTP was positively related with general environmental concern.

References

Arpin-Pont, L., Bueno, M., Gomez, E. and Fenet, H. (2014). Occurrence of PPCPs in the marine environment: a review. *Environmental Science and Pollution Research*: 1-14.

Bu, Q., Wang, B., Huang, J., Deng, S. and Yu, G. (2013). Pharmaceuticals and personal care products in the aquatic environment in China: a review. *J Hazard Mater* 262: 189-211.

Henry, A.D. and Dietz, T. (2012). Understanding environmental cognition. *Organization & Environment* 25(3): 238-258.

Krebs, J.R. (2005). The Croonian Lecture 2004 Risk: food, fact and fantasy. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 360(1458): 1133-1144.

Lawton, R.N. and Rudd, M.A. (2013). Crossdisciplinary research contributions to the United Kingdom′ s National Ecosystem Assessment. *Ecosystem Services* 5: 149-159.

Liu, J.-L. and Wong, M.-H. (2013). Pharmaceuticals and personal care products (PPCPs): A review on environmental contamination in China. *Environment International* 59: 208-224.

Morgan, M.G. and Henrion, M. (1990). Uncertainty: a Guide to dealing with uncertainty in quantitative risk and policy analysis Cambridge University Press.

Rudd, M.A. (2015). Scientists’ framing of the ocean science–policy interface. *Global Environmental Change* 33(0): 44-60.

Serger, S.S., Benner, M. and Liu, L. (2015). Chinese university governance: Tensions and reforms. *Science and Public Policy*.

Stern, P. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of social issues* 56(3): 407-424.

Tong, A.Y., Peake, B.M. and Braund, R. (2011). Disposal practices for unused medications around the world. *Environment international* 37(1): 292-298.

Wang, J., He, B. and Hu, X. (2015). Human-use antibacterial residues in the natural environment of China: implication for ecopharmacovigilance. *Environ Monit Assess* 187(6): 4514.

Wang, M., Webber, M., Finlayson, B. and Barnett, J. (2008). Rural industries and water pollution in China. *Journal of Environmental Management* 86(4): 648-659.

Williams, E.S. and Brooks, B. (2012). Human Health Risk Assessment for Pharmaceuticals in the Environment: Existing Practice, Uncertainty, and Future Directions. *Human Pharmaceuticals in the Environment*. Brooks, B.W. and D.B. Huggett, Springer New York. 4**:** 167-224.

Xi, B., Li, X., Gao, J., et al. (2015). Review of challenges and strategies for balanced urban-rural environmental protection in China. *Frontiers of Environmental Science & Engineering* 9(3): 371-384.

APPENDICES

Supplemental data S1 – Contingent valuation survey scenario presented to respondents

In order to assess respondents' willingness to pay for measures aimed at reducing PPCP pollution they were first given the following background information.

The next series of questions is about Pharmaceuticals and Personal Care Products (PPCPs) and how much if at all you would be willing to pay for measures aimed at reducing the potential harmful effects of these products on the environment. Pharmaceuticals are chemicals of products that are used to diagnose, treat or prevent illness of both human beings and animals, or chemicals of illicit drugs (Sirbu et al. 2006). Personal care products are active ingredients of products that are used directly by the consumers and are mainly used as cosmetics, toiletries, and fragrances (Sirbu et al. 2006), such as bath additives, shampoos, hair tonic, skin care products, hair sprays, setting lotions, hair dyes, oral hygiene products, soaps, sun screens, perfumes, aftershaves, etc. (Daughton and Ternes 1999). PPCPs can enter into the environment through various routes, such as effluent of wastewater treatment plants and landfills (Figure S1 shows the routes of PPCPs into the environment).

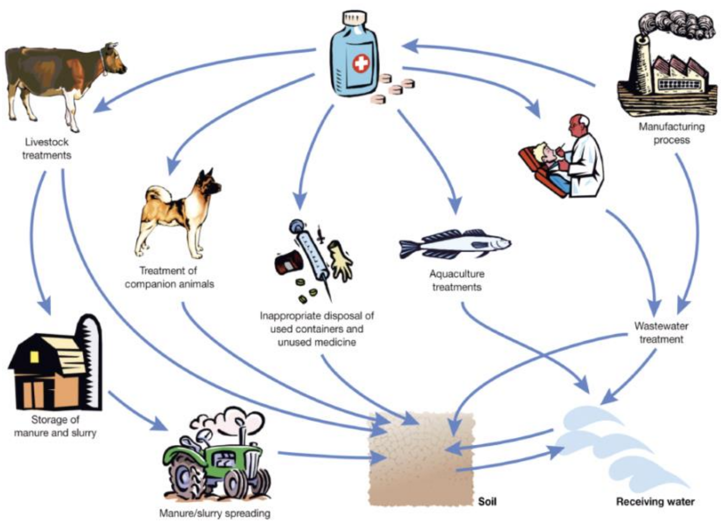

Figure S 1 Routes of Pharmaceuticals entering the environment, adapted from Boxall (2004)

While the effects of PPCPs are not yet fully understood by scientists, it is concerned that they may have potential adverse effects on both ecosystems and human health. For example, trace levels of PPCPs have been shown to have a detrimental impact on wildlife. Marine ecosystems are thought to be especially vulnerable as contamination has been found to harm aquatic species. Some of the known harmful effects on aquatic species include delayed development in fish, and frogs, as well as altered behavior and reproduction. Scientists have found that some chemicals could affect the secretion of male hormones in fish and reduce the number of eggs laid each time. PPCPs in certain circumstances may also lead to antibiotic resistance. This development of resistance could make treating infections more difficult. The consequences for human health of PPCPs in the environment are currently unknown although the enrichment of these kinds of chemicals in animals and humans are significant. For humans, consumption of drinking water, as well as contact through bathing/showering, swimming and finally the consumption of fish have been identified as major potential routes of exposure to PPCPs.

In terms of preventing pollution by PPCPs, there are a number of options available. In particular, there are two programs that the government is considering implementing in order to reduce PPCPs in the environment. One includes equipping sewage treatment plants with filters to separate the PPCPs and also biological treatment. The other option is to fund a nationwide drop off program where residents could return unused PPCPs to pharmacies to be disposed of in a secure and environmentally sound manner. In order to fund these programs (sewage treatment and/or drop off program) it is likely that households will have to charge annual fees to help finance it. With this in mind we are interested in determining what you would be willing to pay for measures aimed at reducing the harmful effects of PPCPs being released into the environment.

When answering the next question, please imagine you are actually paying the amounts specified as higher taxation, above your present contribution. As such consider your available income and other expenses you may have.

Bearing in mind the information presented earlier what are the maximum annual fees that you would be willing to pay to support measures aimed at preventing PPCPs from being released into the environment.

Table S 1 The maximum annual fees that you would be willing to pay

1*	Nothing/￥0	9	￥150	17	￥310
2	￥10	10	￥170	18	￥330
3	￥30	11	￥190	19	￥350
4	￥50	12	￥210	20	￥370
5	￥70	13	￥230	21	￥390
6	￥90	14	￥250	22	￥410
7	￥110	15	￥270	23	￥430
8	￥130	16	￥290	24	￥450

References

Boxall, A. (2004). The environmental side effects of medication. *EMBO reports* 5(12): 1110 - 1116.

Daughton, C.G. and Ternes, T.A. (1999). Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environmental Health Perspectives* 107: 907-938.

Santos, L.H.M.L.M., Araujo, A.N., Fachini, A., et al. (2010). Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. *Journal of Hazardous Materials* 175(1-3): 45-95.

Supplemental data S2 – Censored bid acceptance

Table S 2 Censored bid acceptance

WTP	Freq.	Percent
0	246	40.7
10	75	12.4
30	26	4.3
50	60	9.9
70	4	0.7
90	15	2.5
110	26	4.3
130	13	2.2
150	51	8.4
170	7	1.2
190	3	0.5
210	18	3.0
230	4	0.7
250	12	2.0
270	3	0.5
290	11	1.8
310	9	1.5
330	3	0.5
350	4	0.7
370	1	0.2
390	1	0.2
410	1	0.2
430	3	0.5
450	9	1.5

Supplemental data S3 – Summary statistics of variables used in regression analysis

Table S 3 Summary statistics of variables used in regression analysis

Variables	Description	Mean	Std. Dev.	Min	Max
Dependent variables					
Participation in disposal program	If a disposal program were implemented at local pharmacies where you could return unused medicines or personal care products how likely would you be to return unwanted or expired products for safe disposal? (1=Very unlikely, 2=Unlikely, 3=Neither likely or unlikely, 4=Likely, 5=Very likely)	3.50	1.3	1	5
Willingness to pay	Willingness to pay of respondents for measures aimed at preventing PPCPs pollution	71.92	104.5	0	>450
Explanatory variables					
Aged under 30	Age of the respondents (1=under 30, 0 otherwise)	21.16	0.41	0	1
Age between 30 and 50	Age of the respondents (1 = between 30 and 50, 0 otherwise)	0.50	0.50	0	1
Third level education	Highest level of education that respondents have obtained (1=third level education (e.g. undergraduate or postgraduate degree), 0 = otherwise)	0.49	0.50	0	1
High school education	Highest level of education that respondents have obtained (1=high school education, 0 otherwise)	0.24	0.43	0	1
Dependent children	Whether the respondent has dependent children (1 = Yes, 0 = No)	0.54	0.50	0	1
Female	Gender of the respondents (1=Female, 0=Male)	0.61	0.49	0	1
Middle income	Personal annual income before taxes (RMB) of the respondents. (1= Between 14,400 and 48,000, Otherwise)	0.59	0.49	0	1
High income	Personal annual income before taxes (RMB) of the respondents. (1= Greater than 48,000, 0 otherwise)	0.14	0.34	0	1
Financial status very good or fairly good	Respondents evaluation of the financial situation of their household (1 = Very good or fairly good, 0 otherwise)	0.48	0.50	0	1
Financial status neither good nor bad	Respondents evaluation of the financial situation of their household (1 = neither good nor bad, 0 otherwise)	0.26	0.44	0	1
Expenditure on personal care products	Approximately how much would you spend per month (RMB) on personal care products? (Took the midpoint of each interval for analytical ease - 1% reported an expenditure greater than 500 and these were given a value of 500).	118	110	0-50	>500

Table S 3 Summary statistics of variables used in regression analysis
Continued

Variables	Descriptions	Mean	Std. Dev.	Min	Max
Explanatory variables					
Expenditure on pharmaceuticals	Approximately how much would you spend per month (RMB) on medicines? (Took the midpoint of each interval for analytical ease - 1% reported an expenditure greater than 500 and these were given a value of 500).	102	108	0-50	>500
Awareness	Are you aware that compounds from medicines and personal care products can have a negative effect on the environment? (1=Yes, 0=No)	0.62	0.49	0	1
Very concerned about the environment in general	How concerned are you about the environment in general? (1=Very concerned, 0 otherwise)	0.35	0.48	0	1
Fairly concerned about the environment in general	How concerned are you about the environment in general? (1=Fairly concerned, 0 otherwise)	0.49	0.50	0	1
Very good self-reported health status	Respondents evaluation of their overall health (1 = Very good, 0 otherwise)	0.18	0.38	0	1
Good self-reported health status	Respondents evaluation of their overall health (1 = Good, 0 otherwise)	0.45	0.50	0	1

Supplemental data S4 – Summarization of the literature review on preferences around disposal of PPCPs

Table S 4 Summarization of the literature review on preferences around disposal of PPCPs

Year	Citation	Region	garbage	Sewage	Return to pharmacy or keep at home
2002	COMPAS (2002)	Canada	50%	19%	NA
2006	Abahussain et al. (2006)	Kuwait	77%	11%	NA
2005	Bound and Voulvoulis (2005)	UK	66%	12%	22%
2009	Kotchen et al. (2009)	USA	45%	28%	NA
2009	Persson et al. (2009)	Sweden	3%	NA	55% + 43%

Supplemental data S5 – The reasons of choosing the city of Xiamen to take our survey research

The city of Xiamen

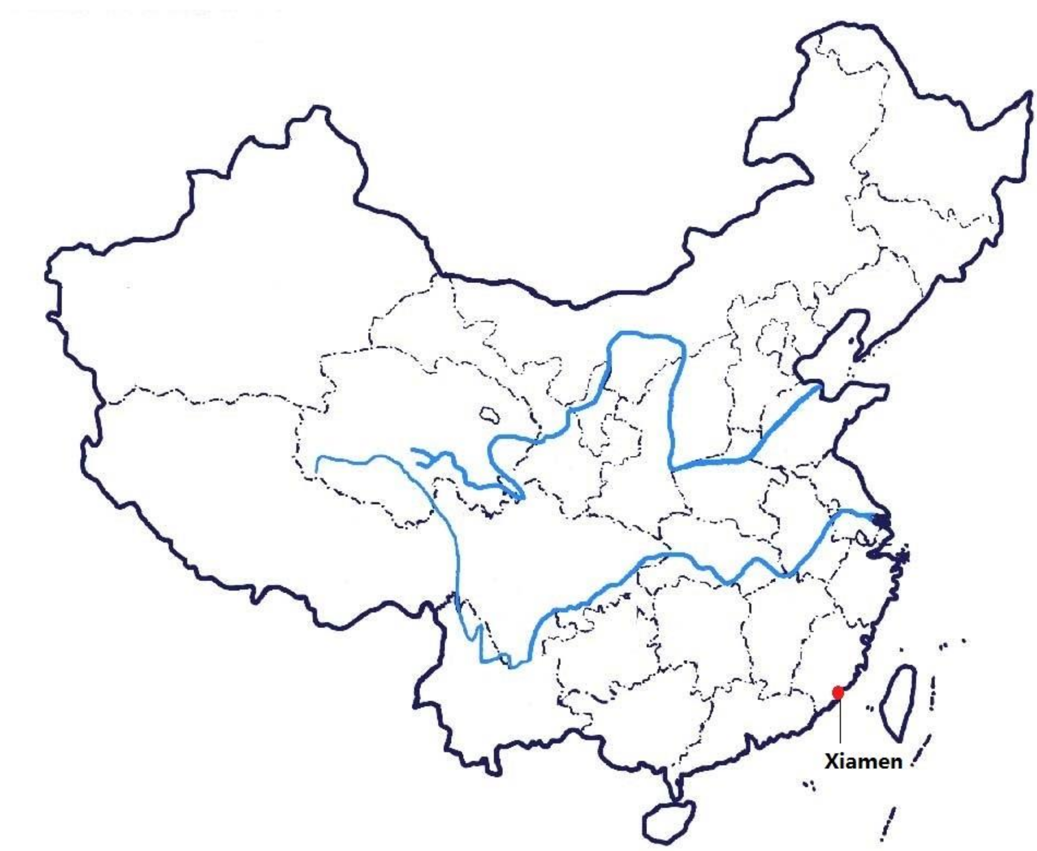

Figure S2 The map of China highlighted with the city of Xiamen

Xiamen is a coastal city located in the southeast of China. It is one of the fifteen sub-provincial cities of China, which, like a prefecture-level city, is governed by the Fujian Province, and is managed independently with respect to economics and law. Xiamen is also one of the four special economic zones that were first conducted the opening-up policy in China. The total population of Xiamen is 3,531,347 (2010 Chinese Census in Xiamen), in which 88.33% of them are living in urban and 11.67% of them are living in countryside, and the population density is 2100/km^2. The city contains six districts, in which Huli and Siming combine the old urban island, and the other four districts

(Haicang, Jimei, Tong’an and Xiang’an) connect with the mainland of China. From 2013 to 2014, the population of Xiamen was ranked at 150th, while the population density of the old urban island of the city is higher than Hong Kong and Singapore; the GDP of Xiamen was ranked at 55th, with per capita GDP is ranked at 38th. Figure S2 shows the map of China on which the location of Xiamen is highlighted in red.

The reason to choose Xiamen for our survey:

The reasons that we chose Xiamen for our survey were:

(1) Xiamen can represent the cities located along the eastern coastal line of China from the population density, universal education, income level, economic development, and cultural open-up aspects;

(2) A series of scientific research on PPCPs in the environment have already been taken in Xiamen. As most of the PPCP-related research of China are taken in the eastern coastal cities, Xiamen can also represent those cities in the scientific aspect;

(3) We can cooperate with the Institute of Urban Environment (IUE) of Chinese Academy of Sciences (CAS) located in Xiamen. IUE have gained a lot of experience on taking survey research in Xiamen and developed robust sampling methods in the light of the specific situation of Xiamen.