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The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Pharmaceuticals in Municipal Sewage Treatment Works of China: Behaviour and Risk Assessment (我國城市污水處理廠中藥物類污染物的行為和風險評估)

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof Paul Kwan-sing LAM	Prof Hanqing YU
Post	Chair Professor	Professor
Unit / Department / Institution	Department of Chemistry / City University of Hong Kong	Department of Chemistry / University of Science and Technology of China
Contact Information	*bhpksl@cityu.edu.hk*	
Co-investigator(s) *(with title and institution)*	Dr. James Chung Wah LAM ((EdUHK , HK)	

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	01-Jan-2013		
Project Completion date	31-Dec-2016		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	31-Dec-2017		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Collect wastewater samples representative of key sewage treatment processes from sewage treatment works (STWs) in coastal cities of China, namely Hong Kong and Shanghai
2. Analyze the levels of 43 pharmaceuticals of 17 therapeutic classes in samples collected from important STWs using analytical procedures previously established in our laboratory
3. Through mass balance analysis, examine the removal efficiencies of these compounds by different sewage treatment processes and compare the efficiencies among different types of sewage treatment works
4. Investigate and identify the key biological factors (e.g. microbial growth inhibition) determining the elimination efficiencies of pharmaceuticals by different sewage treatment processes
5. Assess the potential ecological risks of pharmaceuticals to coastal ecosystems in China

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

In this study, influents and effluents collected from Hong Kong sewage treatment works (STWs) employing different treatment processes were analyzed for 43 pharmaceuticals. Potential antibiotic-degrading bacteria were examined for their abilities to remove antibiotics in the conventional activated sludge treatment process. The effect of the presence of other pharmaceuticals on bacterial degradation of antibiotics was also investigated (Lin et al., 2015; **Publication No. 2 in Part C**).

In 2013, twenty-four strains of microorganisms which were able to resist the action of CLX, ERY, OFX, ROX, and TET were isolated in the activated sludge collected from Hong Kong STWs. Two strains capable of degrading CLX were isolated and identified as strains CE21 and CE22. In terms of removal efficiencies, strain CE22 was found to be more effective than strain CE21 (Figure 1; **Publication No. 2 in Part C**). The results indicate that the removal efficiencies of strains CE21 and CE22 were influenced by the concentration of CLX, as well as the presence of other pharmaceuticals.

Drinking water sources could potentially be contaminated as a result of incomplete removal of contaminants in water treatment plants. In order to assess the potential risks of pharmaceutical exposure in the Chinese population via potable water, 113 household tap water samples were collected from 13 Chinese cities during both dry and wet seasons, and analyzed for 32 pharmaceuticals. Seventeen pharmaceuticals were detected in the tap water samples. Spatiotemporal distributions indicated that cities in the Yangtze River region represented the hot spots, mainly due to contamination by municipal and/or agricultural wastewater. Maximum concentrations of all detectable compounds were observed during the dry season. Results of RQ analyses showed that the potential risks for infants and children were up to five times greater than those for adolescents and adults (Leung et al., 2013; **Publication No. 1 in Part C**).

In 2015, a comprehensive investigation was conducted in 12 STWs located in selected major cities in China to elucidate the spatial distribution of and removal efficiencies for 35 pharmaceuticals. This study tested for 50 pharmaceuticals, and 35 were detected in the influent and/or the effluent samples. Most of the high-concentration pharmaceuticals were antibiotics. Our results show that the removal efficiencies of total pharmaceuticals (35 in total) varied significantly among the 12 STWs, which can be classified according to their treatment processes: SBR; AAO; OD; and AAO+MBR. Results show that the mean removal efficiencies for the different treatment processes varied only slightly from 85.9% to 98.5%, although the removal efficiencies for most individual pharmaceuticals were lower (generally below 80%). We hypothesize that the inconsistency of removal efficiencies between total and individual pharmaceuticals reported in this study is attributed to the extremely high concentrations and high removal efficiencies of several pharmaceuticals, namely acetaminophen, caffeine, salicylic acid, lincomycin, azithromycin and chloramphenicol (Liu et al., 2013; **Publication No. 3 in Part C**). The potential risks of the pharmaceuticals were further assessed by RQs, calculated based on the toxicological data (Table 2; **Publication No. 3 in Part C**) and the measured concentrations in the effluents.

Our results indicate that the concentrations of detected pharmaceuticals varied significantly among different pharmaceutical species and STWs. The concentrations of total pharmaceuticals in STW influent were generally higher in north China than in the south. Among the 35 detected pharmaceuticals, caffeine was the most dominant, while quinolones and macrolides also occurred at high concentrations in most of the STWs. The removal efficiencies of total pharmaceuticals (after excluding six less toxic yet high-concentration compounds) were significantly affected by the treatment processes and pharmaceutical composition. In general, higher removal was found in SBR and AAO+MBR than in AAO and OD processes. Among the many residual pharmaceuticals in the STW effluent, erythromycin-H_2O, clarithromycin, roxithromycin and ofloxacin exhibited very high ecological risks, and thus these pharmaceuticals should be considered as priority contaminants to be controlled in China and in the design/operation of future STWs. The above results have been published in the 2017 issue of Science of the Total Environment (586:1162-1169; **Publication No. 3 in Part C**).

Potential for further development of the research and the proposed course of action
(maximum half a page)

During the course of our investigations, we have taken notice of the fact that many pharmaceuticals have intrinsic chirality, and exhibit species-dependent stereoselectivity in biologically- or microbiologically-mediated processes. The desired effects of many chiral pharmaceuticals are enantiomeric-specific, but only a few studies have been conducted on the enantiomeric fate of chiral pharmaceuticals in the environment. Currently, the ecotoxicity of chiral pharmaceuticals towards aquatic organisms is commonly assessed for racemic forms only (or without any standard protocol as to which enantiomer should be used). In view of the above, it is important to study the stereoselective fate and distribution of chiral pharmaceuticals released from municipal discharges, influents, and effluents from STWs. Specifically, STWs in Hong Kong are characterized by two types of treatments, namely chemically-enhanced primary treatment (CEPT) and secondary (biological) treatment with traditional activated sludge (TAS). Results we have obtained to date indicate that (1) pharmaceuticals, namely atenolol, metoprolol, venlafaxine, and chloramphenicol, show stereoselectivity; (2) all of these pharmaceuticals can be detected in all sewage samples throughout the sampling period; (3) all of these pharmaceuticals are released in greater quantities in the dry season than in the wet season; (4) compared to metoprolol and venlafaxine, atenolol and chloramphenicol, two polar compounds with higher hydrophilicity, are highly susceptible to biodegradation; and (5) all of these pharmaceuticals have their own enantiomeric pairs, and enantioselective enrichment is observed for atenolol and venlafaxine following sewage treatment. Specifically, atenolol undergoes enrichment with (+)-*R*-enantiomer, while venlafaxine is enriched with (–)-*R*-enantiomer. Indeed, results of a preliminary risk assessment suggest that (+)-*R*-atenolol might pose a significant risk to aquatic organisms inhabiting the northwest end of Victoria Harbor. Against such a background, it is instructive to undertake a further study to (1) determine changes in the stereoisomeric composition of chiral pharmaceuticals at various stages of the wastewater treatment processes; (2) compare the changes in stereoisomeric composition of chiral pharmaceuticals between CEPT and TAS; (3) ascertain if there are variations in stereoisomeric composition of chiral pharmaceuticals in different seasons; and (4) evaluate the implications of changes in stereoisomeric composition to the ecological risks of chiral pharmaceuticals.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

In this study, influents and effluents collected from sewage treatment works (STWs) in Hong Kong and major cities in mainland China were analyzed for pharmaceuticals, mainly antibiotics. Water source can be contaminated by municipal and/or agricultural wastewater, and incomplete removal of contaminants in water treatment plants can result in unintentional human exposure to pharmaceuticals. A health risk assessment for exposure to pharmaceuticals via tap water conducted in China shows that the potential risks for infants and children were up to five times greater than adolescents and adults.

An investigation, conducted in 12 Chinese STWs, detected 35 pharmaceuticals in the influent and/or effluent samples. Results indicate that erythromycin-H_2O, sulfamethoxazole, lincomycin and hydrochlorothiazide were widely used in China, while the most frequently detected pharmaceuticals included macrolides, quinolones, lincosamides, and amphenicols. The environmental behaviour and fate of nine groups of seventeen antibiotics were investigated in the 12 Chinese STWs. The 12 STWs can be categorized into four groups according to the applied secondary treatment processes, namely sequencing batch reactor (SBR); anaerobic/anoxic/oxic (AAO); oxidation ditch (OD); and AAO membrane bioreactor (MBR) integrated process. In general, higher removal of pharmaceuticals was observed in SBR and AAO+MBR as compared to AAO and OD processes.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) ***(bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/ Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*						
2013				Leung, H.W., Jin, L., Wei, S., Tsui, M.M. P., Zhou, B., Jiao, L., Cheung, P.C., Chun, Y.K., Murphy, M.B., **Lam, P.K.S.***	Pharmaceuticals in tap water: Human health risk assessment and proposed monitoring framework in China. *Environmental Health Perspectives*. 121, 839 – 846.	Yes (2014)	Yes	Yes	Yes
2015				Lin, B., Lyu, J., Lyu, X., Yu, H., Hu, Z., **Lam, J.C.W.*, Lam, P.K.S*.**	Characterization of cefalexin degradation capabilities of two *Pseudomonas* strains isolated from activated sludge. *Journal of Hazardous Materials.* 282, 158 – 164.	Yes (2014)	Yes	Yes	Yes

2017				Liu, H.Q., **Lam, J.C.W.**, Li, W.W., **Yu, H.Q.*** and **Lam, P.K.S.***	Spatial distribution and removal performance of pharmaceuticals in municipal wastewater treatment plants in China. *Science of the Total Environment* 586, 1162-1169	No	Yes	Yes	Yes

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
8/2013/ Edmonton, Canada	Chemicals of Emerging Concern in China	The 10th International Symposium on Persistent Toxic Substances	No	Yes	Yes	No (attached)
10/2013 Hong Kong, China	Pharmaceuticals in Tap Water: Human Health Risk Assessment and Proposed Monitoring Framework in China	Hong Kong Government Laboratory Centenary Conference	No	Yes	Yes	No (attached)
11/2015 Guangzhou, China	A Study on Several Groups of Chemicals of Emerging Concern	The 8th National Conference on Environmental Chemistry Guangzhou, China	No	Yes	Yes	No (attached)

6/2016 Hong Kong, China	Current Status of Some Important Groups of Emerging Chemicals of Concern in Coastal Region of South China	The 8th International Conference on Marine Pollution and Ecotoxicology	No	Yes	Yes	No (attached)

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Xianjin Lv	Doctor of Philosophy	September 2009	June 2014
Yuefei Ruan	Doctor of Philosophy	September 2014	August 2017

Note:
Dr. Xianjin Lv was recruited under the Joint PhD Programme of City University of Hong Kong (CityU) and University of Science and Technology of China (USTC).
He was jointly supervised by Prof. Hanqing YU (USTC) and Prof. Paul LAM (CityU), who are the PIs of this project.

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*