COMPARATIVE STUDY ON PHARMACEUTICALS RESIDUES IN MUNICIPAL WASTEWATER TREATMENT PLANTS AND RECEIVING WATERS IN THAILAND AND SOUTH KOREA

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Shruti Tewari

COMPARATIVE STUDY ON PHARMACEUTICALS RESIDUES IN MUNICIPAL WASTEWATER TREATMENT PLANTS AND RECEIVING WATERS IN THAILAND AND SOUTH KOREA

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ABSTRACT

Pharmaceuticals in the aquatic environment are of growing concern worldwide for their potential ecological consequences, especially in densely populated cities. However, occurrences, sources and potential risks of pharmaceutical residues have rarely been investigated in Bangkok, Thailand. We collected water samples from five wastewater treatment plants (WWTPs) and six canals of Bangkok as well as in the Chao Phraya River, in three sampling events representing different seasonal flow conditions, i.e., June and September 2011 and January 2012. Water samples were analyzed for twenty three major pharmaceuticals including acetaminophen, acetylsalicylic acid, atenolol, caffeine, chloramphenicol, chlorotetracyclin, ciprofloxacin, diclofenac, enrofloxacin, erythromycin, fenbendazole, florfenicol, ibuprofen, lincomycin, mefenamic acid, naproxen, oxitetracyclin, roxithromycin, sulfamethazine, sulfamethoxazole, sulfathiazole, trimethoprim and tylosin. Overall average level of pharmaceuticals' residues in WWTPs influents in Bangkok was the highest for acetylsalicylic acid (4,699.4 ng/L), followed by caffeine (2,250.5 ng/L) and ibuprofen (701.9 ng/L), and in Seoul, acetylsalicylic acid (70,175 ng/L) was also at the highest level, followed by ibuprofen (4,667.5 ng/L) and naproxen (2,905 ng/L). Overall average concentration in the effluents in Bangkok was the highest for caffeine (307.1 ng/L), followed by acetylsalicylic acid (260.5 ng/L) and mefenamic acid (251.4 ng/L), and in Seoul, mefenamic acid (488.3 ng/L) was at the highest level, followed by naproxen (161.8 ng/L) and roxithromycin (152.3 ng/L). Acetylsalicylic acid was also at the highest level in surface water in Bangkok (on average: 1,355 ng/L in canals and 312.6 ng/L in the river) and naproxen was at the highest level (892.1 ng/L) in Han River in Seoul. Removal efficiencies of WWTPs / STPs for acetaminophen, caffeine, ibuprofen, and naproxen were above 80 %, while those for roxithromycin, sulfamethoxazole and sulfamethazine were negligible. For several compounds, the concentrations in ambient water were higher than those detected in the WWTPs effluents, suggesting contribution of sources other than WWTPs. On an average, concentrations of the detected pharmaceuticals in river and canals, during low flow conditions, were found to be 1.6 to 10.8 times higher as compared to high flow conditions in Bangkok. Average levels of pharmaceuticals' residues were higher in Han River as compared to Chao Phraya River. This could be due to the low flow condition in dry season during the sampling event in Han River. Hazard quotients estimated for acetylsalicylic acid, ciprofloxacin, diclofenac and mefenamic acid in most of the canals and that of ciprofloxacin in river, were greater than or close to 1 suggesting potential ecological risks. Ecological implications of the pharmaceutical residues in Bangkok waterway warrant further investigation.

KEY WORDS: PHARMACEUTICALS / BANGKOK / SEOUL / INFLUENT / EFFLUENT / CANALS / RIVER / HAZARD QUOTIENT

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LIST OF ABBREVIATIONS

Abbreviations and symbols

%	Percent
µg	Microgram
1-R7B	Rama Seven Bridge
2-SL	WatMaha Raj, SanamLuang
3-CK	WatYannawa, ChalermKrung
4-KT	Bangkok Export Office, KlongThoi.
AAP	Acetaminophen
ASA	Acetylsalicylic acid
ATEN	Atenolol
Av	Average
BHB	BangHwa Bridge
CAF	Caffeine
CAP	Chlorampenicol
CN	Chong Nonsi WWTP
CPF	Ciprofloxacin
CTC	Chlorotetracyclin
DCF	Diclofenac
DD	Din Daeng WWTP
Eff.	Effluent
ENRO	Enrofloxacin
et al.	Et alii, and others
ETM	Erythromycin
FBD	Fenbendazole
FFN	Florfenicol
HNB	HanNam Bridge

LIST OF ABBREVIATIONS (cont.)

Abbreviations and symbols

HPLC	High performance liquid chromatography
IBP	Ibuprofen
Inf.	Influent
JR	JungRang STP
JSB	JamSil Bridge
KBJ	Klong Bang Jak
KBL	Klong Bang Lampho
KCN	Klong Chon Nonsi
KKH	Klong Kao Hong
KPK	Klong Phadung Krunkasem
KSS	Klong Sam Sen
L	Liter
LCM	Lincomycin
Max	Maximum
MFN	Mefenamic acid
Mid Pro.	Middle process
Min	Minimum
MPB	MaPo Bridge
MS/ MS	Double mass spectrometry
ND	Not detected
ng	NanoGram
NJ	NanJi STP
NPX	Naproxen
OTC	Oxitetracyclin
PPCPs	Pharmaceuticals and Personal Care Products
RK	Rattanakosin WWTP
RTM	Roxithromycin

LIST OF ABBREVIATIONS (cont.)

Abbreviations and symbols

SMX	Sulfamethoxazole
SMZ	Sulfamethazine
SN	Seonam STP
SP	Si Phraya WWTP
SPE	Solid phase extraction
STPs	Sewage Treatment Plants
STZ	Sulfathiazole
TC	Tancheon STP
TK	Thung Kru WWTP
TMP	Trimethoprim
TYL	Tylosin
USGS	United States Geological Survey
WWTPs	Wastewater Treatment Plants

CHAPTER I
INTRODUCTION

1.1. Statement of the Problem

Many people are unaware that a new health and environmental concern has emerged among scientists around the world - pharmaceuticals and personal care products (PPCPs) in the environment. Until recently, the Environmental Agencies worldwide have been primarily concerned with monitoring and regulating a relatively small number of so-called priority pollutants in air, water, and soil. However, the significantly increasing use of prescription drugs has resulted in the manufacture of literally tens of thousands of new and complex chemicals that enter the environment in large quantities, especially in our wastewater and sewage treatment plants (Anonymous a, 2005).

Pharmaceuticals are basically commercial drugs and medicines that are taken to treat illness, disease, and medical conditions in both humans and animals. Pharmaceuticals include pain killers, anti-inflammatories, antibiotics, antiseptics, beta blockers (e.g., blood pressure medications), lipid regulators (e.g., cholesterol medication), stimulants, antidepressants, tranquilizers, psychiatric drugs, cancer (chemotherapy) drugs, oral contraceptives, synthetic hormones, drugs for enhancing sexual performance (e.g., viagra, levitra) and many other classes and types of drugs. Although a variety of pharmaceutical compounds have been detected in the environment, their potential ecological significance remains unknown, and very few studies have addressed their impact on environment. (Munoz et al, 2009).

Pharmaceuticals and personal care products (PPCPs) are excreted as human or animal waste or are rinsed from our bodies and washed down the drains and sewer systems to be released into the environment in staggering quantities around the world. Many pharmaceuticals and personal care products have persistent chemicals

and compounds that remain biologically active after they leave the body or are disposed in landfills and receiving water bodies. Hospitals, doctors' offices, veterinary clinics, farms, ranches, and average homes are continual sources of PCPPs.

PPCPs are of concern for potential ecological and environmental impacts. They may be active at extremely low concentrations, are widespread and continuously released in large quantities, have unpredictable biochemical interactions when mixed. At times may concentrate in the food chain and especially affect aquatic organisms (Anonymous a, 2005).

Drugs are tested to be safe for humans, only for a particular timeframe (usually over a matter of months) not for lifetime. Pharmaceuticals produce side effects as well as may interact with other drugs at normal medical doses. Due to these reasons, there is growing concern in the scientific community, that certain drugs or combinations of drugs may harm humans over decades because water, unlike most specific foods, is consumed in sizable amounts every day. Our bodies may shrug off a relatively big one-time dose, yet suffer from a smaller amount delivered continuously over a half century, perhaps subtly stirring allergies or nerve damages. Children, pregnant women, the elderly and the very ill might be more sensitive (Roth 2005). Many concerns about chronic low-level exposure focus on certain drug classes, including:

- chemotherapy drugs that can act as a powerful poison
- hormones that can hamper reproduction or development
- medicines for depression and epilepsy that can damage the brain or change behavior
- antibiotics that can allow human germs to mutate into more dangerous forms

Some of the known potential impacts on organisms include delayed development in fish, delayed metamorphosis in frogs, and a variety of reactions including altered behavior and reproduction. Researchers at several universities have

recently discovered that a group of antidepressants, including drugs like prozac, zoloft, paxil, and celexa may be found in frogs and fish and significantly slow their development. (Anonymous a, 2005; Fick et al., 2009; Kolpin et al., 2002; Fent et al., 2006).

It is quite obvious that our precious water resources are being threatened by the pharmaceuticals contamination with higher and higher levels detected in receiving water bodies (Erwin, 2005).

1.2. Background Information

Millions of prescription and nonprescription drugs are purchased and ingested by or applied on individuals. Ingested drugs are eventually excreted from individuals through urine or feces. High percentages of many pharmaceuticals can be excreted from the body un-metabolized and enter wastewater as biologically active substances (Buhner, 2002). According to a report, 90% of the drug, propofol found in anesthesia, is excreted unmetabolized. This is a very high percentage and it illustrates that large amounts of various unmetabolized pharmaceuticals are being released into wastewater where their environmental impacts are not well known (Kummerer, 2002). Pharmaceuticals are products not only being released after usage but also during manufacturing and disposal of unused or expired drugs (Boxall, and Roger, 2003).

Many pharmaceuticals are often persistent and lipophilic - able to pass through cell membranes, which allow them to carry out specific biological functions. Many pharmaceuticals are relatively stable to avoid being biologically inactivated before carrying out the intended pharmaceutical effects in the body. Unmetabolized pharmaceuticals are often the most non-biodegradable substances in the environment. Their inherent medicinal properties give them the tendency to bioaccumulate in other organisms besides humans and thereby potentially provoke effects on the biota of aquatic and terrestrial ecosystems (Roth, 2005).

Human use of pharmaceutical drugs has increased to extremely high levels. Several kilotons of nonsteroidal anti- inflammatory drugs, such as ibuprofen, alone are produced annually worldwide (Kolpin et al., 2002; Cleuvers, 2003; Fent et al., 2006; Carlsson et al., 2009). Pharmaceuticals eventually get washed from the body and enter water systems, ultimately winding up in the effluent of wastewater treatment plants and aquatic environments. Since medical substances are developed with the intention of performing some sort of biological function, they have a tendency to bioaccumulate and induce effects in aquatic and terrestrial ecosystems. The individual rarely gives a second thought about where those products are going. Who would have imagined that estrogen from birth control pills could eventually wind up in drinking water and potentially contribute to young girls to entering puberty early?(Bertuglia et al., 2008; Derbyshire, 2010).

It has been reaffirmed by the scientific community that pharmaceuticals are being released into the environment in enormously large quantities on a regular basis. The exact effects that each drug is having on ecosystems, biota, and humans, however, are still are not completely understood. Therefore, more research on occurrence and fate of pharmaceutical residues in the wastewater treatment plants (WWTPs) and receiving water bodies are critically needed.

1.3. Objectives

The overall objective of this study was to investigate the situation of occurrence and fate of pharmaceuticals residues in the municipal wastewater treatment plants (WWTPs) and in the downstream receiving water bodies in two Asian cities: Bangkok, Thailand and Seoul, Korea. The specific objectives of this study included:

1.3.1 To investigate the profiles of 23 target pharmaceuticals in five selected municipal wastewater treatment plants (WWTPs) and in downstream receiving water bodies near the discharge points in Bangkok, Thailand.

1.3.2 To investigate the profiles of 23 target Pharmaceuticals in four sewage treatment plants (STPs) and in downstream receiving water of Han River in Seoul, South Korea and to compare with the situation in Bangkok, Thailand.

1.3.3 To evaluate the effects of precipitation and population served by the treatment plants on the levels of pharmaceuticals residues.

1.3.4 To evaluate the effect of treatment processes on removal of pharmaceuticals in WWTPs.

1.3.5 To obtain the ecological risk on aquatic environments due to the presence of pharmaceuticals residues in WWTPs effluents, canals and Chao Phraya River, in Bangkok, Thailand.

1.4. Scope of the Study

Experiments of this study were carried out separately in Bangkok, Thailand and Seoul, South Korea. Laboratory analyses involved two steps:

I. Solid phase extraction (SPE) of water/ wastewater samples.

II. Using high performance liquid chromatography- mass spectrometry-mass spectrometry (HPLC/ MS/ MS) to analyze the concentrations of target pharmaceuticals.

The scope of the conducted research work is shown below

1.4.1 Study was conducted at the five wastewater treatment plants (WWTPs), six canals and Chao Phraya River in Bangkok, Thailand; and four sewage treatment plants (STPs) and Han River in Seoul, South Korea.

1.4.2 Sampling was carried out one time in Seoul, South Korea and three times in Bangkok, Thailand and in separate events in eleven months period during (March 2011; June 2011; September 2011 and January 2012).

1.4.3 Rainfall data was obtained for the sampling periods.

1.4.4 Information was gathered regarding the population served by the treatment plants selected for this study.

1.4.5 The target pollutants were: acetaminophen, acetylsalicylic acid, atenolol, caffeine, chloramphenicol, chlortetracycline, ciprofloxacin, diclofenac, enrofloxacin, erythromycin, fenbendazole, florfenicol, ibuprofen, lincomycin, mefenamic acid, naproxen, oxytetracycline, roxithromycin, sulfamethazine, sulfamethoxazole, sulfathiazole, trimethoprim and tylosin.

1.4.6 Grab samples of water/wastewater were collected from the influent, effluent, as well as at the middle process in WWTPs/STPs and surface waters in Seoul, South Korea and Bangkok, Thailand.

1.4.7 All the samples obtained in Bangkok were concentrated by solid phase extraction in Environmental Engineering Laboratory, Faculty of Engineering at Mahidol University. The extracted samples were shipped to School of Human and Environmental Science, Eulji University, South Korea for HPLC/MS/MS analyses.

CHAPTER II
LITERATURE OF REVIEW

2.1 What are the Pharmaceuticals and Personal Care Products (PPCPs)?

PPCPs are a diverse group of chemicals that have received comparatively little attention as potential environmental pollutants (Christian & Tammy, 2002). Pharmaceuticals comprise an array of products, including a variety of chemical formulations and multiple biological targets. These drugs exert specific biological effects and are administered for human and veterinary health care (Munoz et al., 2009). Most of the peoples take some kind of medication, whether it's a prescription drug or an over-the-counter product. Most of them probably have an out of date bottle of something in our medicine cabinets and wondered what to do with it. Before flush that medication or pour it down the drain, learn more about an emerging issue of concern - pharmaceuticals and personal care products (PPCPs) in water supplies (Daughton and Ternes, 1999 ; Halling-Sorensen *et al*., 1998; Jorgensen and Halling-Sorensen, 2000; Kümmerer, 2001; Heberer, 2002; Anonymous b, 2010).

As a diverse group of chemicals, PPCPs includes:

- Prescription and over-the counter therapeutic drugs.
- Veterinary drugs.
- Dietary supplements.
- Diagnostic agents.
- Nutraceuticals (e.g., vitamins).
- Other consumer products, like fragrances, cosmetics and sunscreens, laundry and cleaning products.

- All the inert, or inactive, ingredients that are part of these products, which can often be just as or more harmful than a product's active ingredients.

PPCPs and their metabolites are continually introduced into the aquatic environment and are prevalent at detectable concentrations (Kolpin, et al., 2002), which can affect water quality and potentially impact drinking water supplies, and ecosystem and human health (Heberer , 2002b, Ying et al., 2004).

Pharmaceuticals are designed to stimulate a physiological response in humans, animals, bacteria or other organisms. During the past decade, concern has grown about the adverse effects the use and disposal of pharmaceuticals might potentially have on human and ecological health. Research has shown that after passing through wastewater treatment, pharmaceuticals, amongst other compounds, are released directly into the environment (Kummerer, 2003).

2.2 Origins and Pathways of the Pharmaceuticals and in the Environment

The concern for pharmaceuticals and personal care products (PPCPs) as toxic substances in the environment and the need to assess their environmental risk have greatly increased since the early nineties. Several reviews dealing with the exposition and effect of pharmaceuticals have been published during the past decade (Daughton and Ternes, 1999; Jorgensen and Halling-Sorensen, 2000; Kummerer, 2001; Ying et.al., 2004). These reviews allow identifying more than one hundred pharmaceuticals and personal care products from various prescription classes measured in wastewater treatment plants (WWTPs) all around the world (Miege et al, 2010).

PPCPs enter the environment and become contaminants in several ways, such as:

• ***Excretion by humans and domestic animals*** - All the components of each pharmaceutical and over-the-counter medication aren't fully metabolized by humans and animals, and the unmetabolized portions of these compounds are excreted from the body as waste.

• ***Disposal of unneeded or expired*** - *PPCPs by flushing them down a toilet or drain* - Some experts recommend flushing as a safe method of PPCP disposal. Flushing does prevent accidental ingestion, but can cause eventual pollution of ground and surface water (Fig. 2.1).

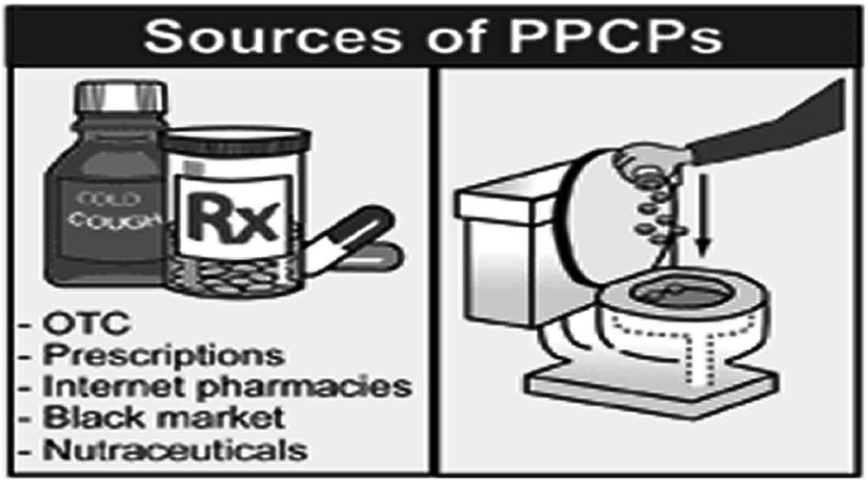

Fig 2.1 Discarding unused drugs and personal care products down the toilet (U.S. EPA, 2010)

• ***Bathing and swimming*** - Compounds from products such as cosmetics, lotions and sunscreen enter surface water bodies through direct contact.

• ***Discharge from municipal sewage systems or private septic systems*** - *Municipal* wastewater treatment plants generally don't treat for the compounds found in PPCPs, so they are present in treated wastewater and discharged into surface water bodies. Septic system owners need to be especially careful about not flushing PPCPs down the toilet or drain – some PPCPs can disrupt the processes in a septic system, posing a risk of groundwater contamination from PPCP compounds and fecal matter. PPCPs also enter the environment through leaching from landfills; runoff from confined animal feeding operations; discharge of raw sewage from (Anonymous g, 2007).

PPCPs, passing through the wastewater treatment systems are continuously entering the receiving water environments via effluent discharges and are present in the sources of public water supplies (groundwater, bank filtrates, and surface water) of waterworks. In some cases even drinking water is contaminated with PPCPs. The entry paths of pharmaceutical products into the environment can be seen as below in Figure 2.2.

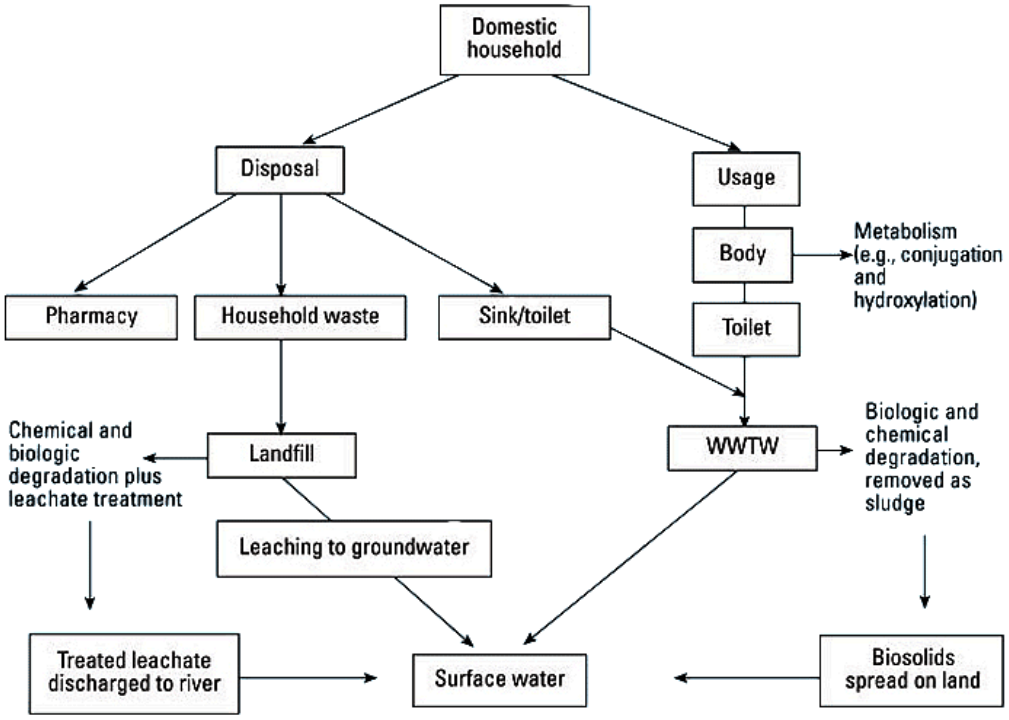

Fig. 2.2 Sources and Pathways of pharmaceuticals from domestic households to the environment (Bound and Nikolaos, 2005)

Pharmaceuticals and personal care products are introduced to the environment as pollutants in a variety of ways. For example, excretion by humans and domestic animals, intentional disposal of unneeded PPCPs (flushing), bathing or swimming, discharge from municipal sewage systems or private septic systems, leaching from landfills, runoff from confined animal feeding operations, discharge of raw sewage from storm overflow events, cruise ships(millions of passengers per year), and some rural homes directly into surface water; accidental discharges to a groundwater recharge area, loss from aquaculture and spray-drift from antibiotics used on food crops etc (Anonymous g, 2007). The major source of PPCPs to environment

is municipal effluents, still up to what % PPCPs can be removed by treatment process are not known.

Figure 2.3 shows, possible sources and pathways for the occurrence of PhAC residues in the environment.

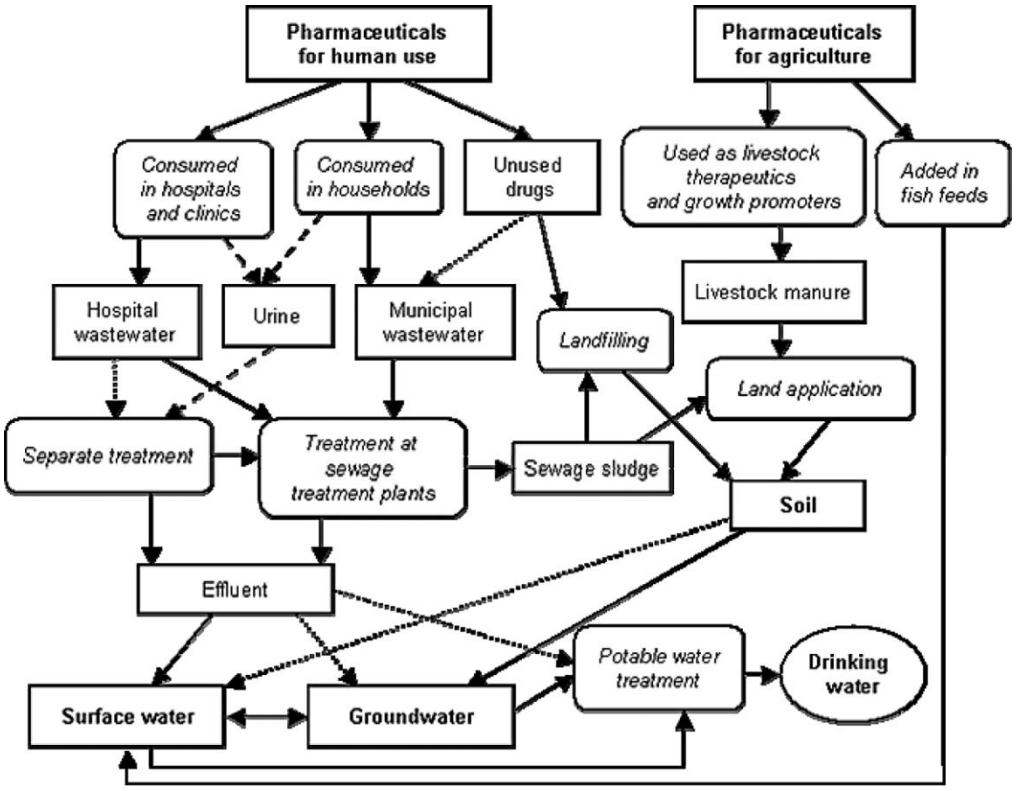

Fig. 2.3 Scheme showing possible sources and pathways for the occurrence of pharmaceutical residues in the aquatic environment (Heberer, 2002)

2.3 The Occurrence and Levels of Pharmaceuticals in the Environment

A vast number of PPCPs have now been detected in surface waters across the world. For human PPCPs, effluent-dominated ecosystems appear to represent worst-case scenarios for waterborne exposure and potential adverse effects. For veterinary medicines, inputs from manure application to soils and the use of

aquaculture are probably the most important exposure routes. The nature of exposure to human PPCPs and veterinary medicines are also very different (Brooks et al., 2009).

EDC and PPCP have been detected in treated wastewater effluents at concentrations ranging from ng/L to μg/L, possibly due to incomplete removal during sewage treatment. Commonly reported EDCs in reclaimed waters include estrogens (estradiol, and estrone), the contraceptive drug ethynylestradiol, and surfactant degradation products nonylphenols (NP) and octylphenol (OP) and their mono- and diethoxylates (NPE1 and NPE2). In effluents from treatment plants, hormones are generally detected at low (<10) ng/L concentrations, whereas the alkylphenols and their ethoxylates are found in the range of μg/L range. All of these compounds have shown estrogenic activities to varying degrees of potency, and can cause feminization of male fish at elevated concentrations in aquatic environments (Purdom, et al., 1994). However, the EDCs such as estradiol and nonylphenols have been found to be susceptible to biodegradation under aerobic conditions whereas, some other known and potential EDCs (e.g. PCBs, DDT and their metabolites) present at trace levels in effluent are much more persistent in the environment (Ying et al., 2004).

A nationwide survey conducted by the U.S. Geological Survey in 1999-2000, brought attention to PPCPs in water, in a sampling of 139 streams in 30 states for 95 organic wastewater compounds, including some pharmaceuticals. At The most common pharmaceuticals detected were steroids and nonprescription drugs. Acetaminophen, the antibiotic trimethoprim and codeine was found in 23.8%, 27.4% & 10.6% of streams tested respectively (Kolpin et al., 2002).

In a study, a screening analysis was conducted in 2004 for 24 PPCPs in tertiary wastewater treatment plant effluents and nearby wells and creeks in the Sequim-Dungeness area of northwest Washington State. The 16 compounds: Acetaminophen, Caffeine, Carbamazepine, Cimetidine, Codeine, Cotinine, Diltiazem, Hydrocodone, Ketoprofen, Metformin, Nicotine, Paraxanthine, Salbutamol, Sulfamethoxazole, Trimethoprim, and Estrone were detected in one or both effluents (well and creek). Concentrations ranged from 0.26 ng/L (Estrone) to 200 ug/L (Paraxanthine). Only Caffeine, Nicotine, and the diabetes drug Metformin (tentatively

identified) were consistently detected in the well and creek samples; concentrations were 25 µg/L or less (Johnson et al., 2004).

In a recent investigation of sediment contaminants in the lower Columbia Basin conducted by USGS a number of pharmaceutical compounds were detected including: Caffeine, trimethoprim,thiabendazole, diphenhydramine, diltiazem, venlafaxine, fluoxetine, citalopram and carbamazapine at concentrations ranging from 2 to 150 ng/g sediment. Additionally, codeine, dehydronifedipine, miconazole, azithromycin and cimetidine were detected at or below the level of the lowest standard (~0.4 and 28 ng/g sediment) depending on the compound. The highest frequency of detection for these compounds was found in the tributaries (Nilsen et al., 2007).

In 2009, an Associated Press investigation found pharmaceuticals in nearly every drinking water supply that they tested, including those of 24 major metropolitan areas across the nation. A vast array of pharmaceuticals - including antibiotics, anti-convulsants, mood stabilizers, sex hormones have been found in the drinking water supplies of at least 41 million Americans (Associated Press, 2009).

According to a news article published in The Washington Times in January, 2009, “When researchers analyzed vials of treated wastewater taken from a plant where about 90 Indian drug factories dump their residues, they were shocked. Enough of a single, powerful antibiotic was being spewed into one stream each day to treat every person in a city of 90,000. It was found that 100 pounds a day of ciprofloxacin running into the stream and it wasn't just ciprofloxacin being detected. The supposedly cleaned water was a floating medicine cabinet a soup of 21 different active pharmaceutical ingredients, used in generics for treatment of hypertension, heart disease, chronic liver ailments, depression, gonorrhea, ulcers and other ailments. Half of the drugs measured at the highest levels of pharmaceuticals ever detected in the environment. The wastewater downstream from the Indian plants contained 150 times the highest levels detected in the U.S.” (Mason, 2009).

2.4 Factors Affecting the Pharmaceuticals' Concentrations and their Removal in WWTPs

The pharmaceuticals concentration in the WWTP effluent varies with the sampling time and seasons. According to Daughton (2001), the overall effectiveness of removal of pharmaceuticals by WWTPs can fluctuate with time of day due to composition and volume of WWTP influents, which depend on the daily activity, as well as with factors varying with season such as temperature, nutrient loads. Consequently, the characteristics of WWTP effluents are varying. Different sampling times may also result in fluctuating drug contents in wastewater, similar to the temporal variations in ammonia, BOD and pH, etc.

The fate of micropollutants during wastewater treatment depends on physico-chemical properties of the compound and operational parameters of WWTPs (such as biomass concentration, sludge retention time, hydraulic retention time, temperature and pH). In the literature, sorption and biodegradation are reported to be two of the most important removal processes of micropollutants from wastewater and both processes are correlated with the availability of the substrate to the degrading microorganisms (Clara et al., 2004; Clara et al., 2005; Joss et al., 2005).

WWTPs were not specifically designed to remove pharmaceuticals. The elimination rate can vary from negligible to more than 99% (Ternes 1998). Biodegradation and sorption could be involved in the elimination process for the drugs (Ternes 1998; Xia et al. 2005). In addition, chemical degradation processes, such as hydrolysis and photolysis, can reduce the concentration of pharmaceuticals in wastewater (Velagaleti and Gill 2001).

2.5 Harmful Effects of Pharmaceuticals

When any human or animal is given any drug, it can either fully or poorly be absorbed. The Remaining part of the medicine which is not absorbed by them passes in to the environment along with faeces. Because of the high solubility of most PPCPs, aquatic organisms are especially vulnerable to their effects. The bio-accumulation nature of drug, once excreted into the environment enters food chains and gets concentrated as these moves upward into larger predators (Rehman et.al., 2007). These studies are very important because drug residues found in the aquatic environment usually occur as mixtures, not as single contaminants. Therefore, scientific assessment of risk to the aquatic environment should definitely consider this complex exposure situation. For this purpose, ecotoxicologists use concepts originally developed by pharmacologists in the first half of the 20th century to predict the toxicity of mixtures. In the present study, the concept of concentration addition was applied (Cleuvers, 2004).

2.5.1 Harmful Effects of Pharmaceuticals Residues on Humans

Research has shown that PPCPs are present in water bodies throughout the world. While some studies have suggested that these substances cause ecological harm, no studies have shown a direct impact on human health. More research is needed to determine the effects on humans of long-term exposure to low levels of PPCPs. The full effects of mixtures of low concentrations of different PPCPs are also unknown (Anonymous d, 2010).

Many Pharmaceutically active compounds (PhACs) contain the chemicals that are mimic the harmful hormones disrupting the human endocrine systems, e.g. the pituitary gland, the thyroid and parathyroid glands, the adrenal glands, the kidney, pancreas and the testes (ovaries, in women), etc. (Anonymous e, 2010). Endocrine disrupting chemicals (EDCs) can affect our bodies in a number of ways they may:

- reduce the production of hormones in endocrine glands,
- affect the release of hormones from endocrine glands,
- copy or counteract the action of hormones at target tissues, or

• speed up the metabolism of hormones and so reduce their action.

In many cases, it is not yet clear exactly how EDCs act, even in some cases where a link has been shown between endocrine disruptor chemicals (EDC) (Anonymous g, 2010).

Based on a recent report, environmental contaminants such as pharmaceutical residues may also have a correlation with human health and demographics e.g. concerning the rising rates of breast cancer, early onset of puberty in girls and the slowly shifting ratio of males to females born in the U.S., all of which can be attributed to estrogenic effects (Woodling et al., 2006; Bertuglia et.al., 2008).

However, there is very little quantified evidence for the effects of long-term, low-dose exposure to endocrine disruptors on such human health problems such as cancer, early onset of puberty, and other medical issues associated with elevated hormone levels. The concentrations of many such contaminants are below the regulatory limits, and are not known to be harmful in such low amounts. In fact, one desk-based study out of Great Britain suggests that emerging contaminants (EC) levels detected in drinking water were so low that they should not be considered harmful at all. However, scientists are not sure what exactly the human health impacts are, and which drugs, or combination of drugs, and at what level they may become toxic (Bertuglia et al. 2008; Thomas et al., 2010).

2.5.2 Harmful Effects of Pharmaceuticals Residues on Other Species

Many xenobiotic compounds introduced into the environment by human activity have been shown to adversely affect wildlife. Reproductive disorders in wildlife include altered fertility, reduced viability of offspring, impaired hormone secretion or activity and modified reproductive anatomy. It has been hypothesized that many of these alterations in reproductive function are due to the endocrine disruptive effects of various environmental contaminants. The endocrine system exhibits an organizational effect on the developing embryo. Thus, a disruption of the normal hormonal signals can permanently modify the organization and future function of the reproductive system (Guillette et al., 2000).

Development of antibiotic resistance in pathogens in the environment owing to their exposure was the major concern. Some prominent examples of drugs causing harmful effects on environment are that of vultures' death after consuming carcasses of animals treated with Diclofenac sodium (Oaks et al., 2004), Ethinyl estradiol adversely affecting fish through its "feminization" of males (Costello, 2004; Fahrenthold, 2004; Woodling et al., 2006) antidepressant drugs like Fluoxetine (Prozac) triggering spawning in shellfish and traces of Cocaine detected in River Thames (Orr and Goswami, 2005). A few drugs are so synthesized that they tend to persist in the environment even after their excretion. Clofibric acid in the aquatic environment disturbing the local fauna is an example (Rahman et al., 2007).

Because of high solubility of most PPCPs, aquatic organisms are especially vulnerable to their effects. Biological tests on various aquatic organisms showed some toxicological effects of diclofenac. Chronic toxicity tests on reproduction (7 days) of *ceriodaphnia dubia* showed the no observed effective concentration (NOEC) value of 1 mg/L. Survival test (10day) on *danio rerio* (zebra fish) showed the NOEC value of 4 mg/L. For acute toxicity evaluation, survival test (48h) on *daphnia magna* showed NOEC value of 22.4 mg/L (National Institute of Environmental Research, 2010).

Researchers have found that a class of antidepressants may be found in frogs and can significantly slow down their development. The increased presence of estrogen and other synthetic hormones in wastewater due to birth control and hormonal therapies has been linked to increased feminization of exposed fish and other aquatic organisms (Anonymous g, 2007).

Professor Woodling of the University of Colorado found that the fish population, downstream of wastewater treatment plants in Boulder Creek were disproportionately female and nonfemale fish had developed both male and female organs (Woodling et al., 2006). These findings are similar to studies done in Lake Mead, Florida, and the Great Lakes, where similar reproductive issues occur in fish, alligators, and birds (Avasthi, 2007; Bertuglia et al., 2008).

Two recent studies conducted in the lower Potomac River in West Virginia as well as in Boulder Creek in Colorado State in USA have also provided evidence of hermaphroditic or inter-sex smallmouth bass and other smaller fish in waters that showed readable levels of endocrine disruptors (Avasthi, 2007; Woodling et al., 2006). Many studies on aquatic lives have shown very similar results (Purdom, 1994, Uyaguari et.al., 2009, Ramirez et.al., 2009, Zeilinger et.al., 2009, Carlsson et.al., 2009). Several of these studies were able to duplicate their results in laboratory tests. The presence of estrogens and estrogen mimicking chemicals from pharmaceuticals, personal care products like lotions, shampoos, and cleansers are thought to be to blame for the endocrine disruption and resulting sexual deformities. Endocrine disrupting compounds can also be found in pesticides and their residuals, fire retardants, plasticizers, and other common chemicals and their byproducts (Bertuglia et al., 2008).

2.5.3 Harmful Effects of Pharmaceuticals Residues on Environment

The concentrations of the PPCPs found in the environment are typically less than therapeutic doses & its complete effect on the environment cannot be understood (Daughton & Ternes, 1999). There is concern about harmful potential of these PPCPs because these may act unpredictably when mixed with other chemicals of the environment or concentrates in the food chain. Additionally, some PPCPS are active at very low concentrations and are often released continuously in large or widespread quantities (Anonymous a, 2005).

2.5 Past studies

2.5.1 Occurrence of Pharmaceutical Residues in Water Environments

Water environments around the world are polluted from our usual intake and excretion of pharmaceutical drugs. Over the past 2 decades, there have been numerous reports on the occurrence of pharmaceutical compounds found in water resources and drinking water supplies. More than 80 compounds of pharmaceuticals

and several drug metabolites have been detected in the aquatic environment around the world.

Only few investigations have been reported on the findings of medical substances in other field samples than sediment or treated waste water samples. Several such compounds seem to be persistent in the environment. An earlier review report outlined the different anticipated exposure routes of pharmaceuticals to the environment and summarized the legislation on the subject (Halling-Sorensen,1998).

Several monitoring studies carried out in Berlin during 1996 and 2000, PhACs such as clofibric acid, diclofenac, ibuprofen, propyphenazone, primidone and carbamazepine were detected at individual concentrations up to the μg/l-level in influent and effluent samples from STPs and in all surface water samples collected downstream from the STPs. Several compounds found at individual concentrations up to 7.3 μg/l in groundwater aquifers near to contaminated water courses. A few of the PhACs were also identified at the ng/l-level in Berlin tap water samples (Heberer, 2002).

A review of the published literature was carried out to identify significance of pharmaceutical compounds to water supplies in the United States. Based on the review, it was concluded that approximately 40 compounds could be present in municipal wastewater effluent at concentrations above 1,000 ng/L and at least 120 compounds could be present at concentrations above 1 ng/L. Important classes of prescription drugs include analgesics, beta-blockers, and antibiotics. Concentrations ranging from approximately 10- 3,000 ng/L for high use pharmaceuticals such as beta - blockers (e.g., metoprolol, propranolol) and acidic drugs (e.g., gemfibrozil, ibuprofen) (Sedlak and Karen, 2001). According to similar review work, pharmaceuticals have been detected in surface water, ground water and drinking water. Only little is known about the significance of emissions from households and hospitals. A brief summary of input by different sources, occurrence, and elimination of different pharmaceutical groups such as antibiotics, anti-tumour drugs, anaesthetics and contrast media as well as adsorbable organically bound halogens (AOX) resulting

from hospital effluent input into sewage water and surface water have been presented (Kummerer , 2002).

In an experimental study, investigations were carried out to analyze the overall ecotoxicological effects of pharmaceutically active compounds (PhACs) in the effluents of Korean wastewater treatment plants (WWTPs) on Daphnia magna. The bioassay results showed no-observed-effect concentrations to median lethal concentrations, ranging from a few to tens of ppm levels for nine PhACs in 48-h acute and 21-d chronic tests. The residual levels were found to be at concentrations ranging from 10 ng/L to 89 mg/L in the influents and from 10 ng/L to 11 mg/L in the effluents from the WWTPs in four metropolitan cities in South Korea between January and November of 2004 (Han et al., 2006). In a similar study, occurrence and biodegradability was investigated for 18 selected PPCPs in Baltimore Back River Wastewater Treatment Plant (BRWWTP) in Baltimore, MD, USA. Overall, 16 selected PPCPs were detected in raw sewage samples; ten were detected in the treated sewage effluents. The majority of the target analytes were detected in both the influent and effluent WWTP samples at µg/L levels, although some PPCPs (e.g.,naproxen and ibuprofen) were encountered at mg/L levels (Yu et al., 2006).

In a recent study, ten wastewater treatment plants in Japan were surveyed to clarify the occurrence and fate of pharmaceuticals and personal care products (PPCPs) in wastewater systems. The concentration of most PPCPs in influent wastewater ranged from 100 - 1000 ng/L and that several patterns of PPCP removal in the treatment process existed according to the characteristics of PPCPs (Suzuki, et.al, 2007). In another similar study, the occurrence of some pharmacuticals: ciprofloxacin, sulfamethoxazole, tetracycline, and trimethoprim antibiotics were investigated in four full-scale wastewater treatment plants. The detected concentrations at µg/L levels ranged from 0.20 to 1.4 for ciprofloxacin, 0.21 to 2.8 for sulfamethoxazole, 0.061 to 1.1 for tetracycline, and 0.21 to 7.9 for trimethoprim. The overall percent difference in the antibiotics' concentrations in the effluents and influents differed between plants and ranged from 33% to 97% (Batt et al.,2007).

According to an another study, the levels of pharmaceutical residues in the influents in four sewage treatment plants (STPs) in South Korea, were the highest for

acetaminophen (average 27,089 ng/L), followed by caffeine, cimetidine, sulfamethoxazole (23,664 ng/L, 8045 ng/L, and 523 ng/L respectively). In effluent samples, cimetidine showed the highest level (5380 ng/L), followed by caffeine, sulfamethoxazole and carbamazepine (278ng/L, 193 ng/L, 111 ng/L respectively). In surface water, the concentration of cimetidine was also the highest samples (average 281 ng/L), which is the highest level reported from surface water worldwide. Caffeine (268.7 ng/L), acetaminophen (34.8 ng/L), and sulfamethoxazole (26.9 ng/L) were also detected in relatively high levels (Choia et al., 2008). A similar investigation was done to investigate the residues of nineteen PPCPs in three urban streams and the Major Pearl River at Guangzhou, South China. Estrone was detected in >60% water samples with a maximum concentration of 65 ng L−1. Endocrinedisrupting phenols were found to be widely present at rather high concentrations in the urban riverine water of Guangzhou. Salicylic acid, clofibric acid and ibuprofen were detected in most water samples with maximum concentrations of 2098, 248 and 1417 ng L−1 respectively. The detection frequencies and median concentrations of the PPCPs appeared higher during the low-flow season than during the high-flow season (Peng et al. 2008).

Another recent study was carried out to analyze pharmaceuticals in the effluent from a wastewater treatment plant serving about 90 bulk drug manufacturers in Patancheru, near Hyderabad, India. The concentration of the most abundant drug, ciprofloxacin was found up to 31,000 μg/L (Larssona et al., 2007). In a follow up research work, samples were collected from the recipient stream and from two lakes along with wells in six nearby villages that were not contaminated by the treatment plant. Ciprofloxacin, enoxacin, cetirizine, terbinafine, and citalopram were detected at more than 1 mg/L in several wells. Very high concentrations of ciprofloxacin (14 mg/L) and cetirizine (2.1 mg/L) were found in the effluent of the treatment plant, together with high concentrations of seven additional pharmaceuticals. Very high concentrations of ciprofloxacin (up to 6.5 mg/L), cetirizine (up to 1.2 mg/L), norfloxacin (up to 0.52 mg/L), and enoxacin (up to 0.16 mg/L) were also detected in the two lakes (Fick et.al., 2009).

The Preliminary results of an ongoing current project by the Southern California Coastal Water Research Project Authority show that many PPCPs and industrial compounds were present in wastewater effluents. These findings indicate that aquatic life is exposed to a wide variety of emerging contaminants, even after 100- to 1000-fold dilutions of wastewater effluent in the ocean (Anonymous f, 2010).

2.5.2 Toxicity and Harmful Effects of Pharmaceutical Residues

Pharmaceutical residues in the environment, and their potential toxic effects, have been recognized over the period. Due to physico-chemical behavior and other harmful xenobiotics which are persistent or produce adverse effects, Pharmaceutical residues as potential pollutants becomes one of the emerging research area in the environmental chemistry (Hernando, et.al., 2006).

A study was done (Purdom, C.E., 1994) to test, that sewage effluent might contain a substances, estrogenic to fish. Laboratory studies on the potency of ethynylestradiol demonstrated that levels as low as 0.1 to 0.5 ng 1^{-1} could produce a positive response. An extensive nationwide survey was conducted in UK, cages containing rainbow trout in the effluent from sewage-treatment works were placed for three weeks. Exposure of trout to effluent resulted in a very pronounced increase (500 to 100,000-fold, depending on site) in the plasma vitellogenin concentration. Induction of vitellogenesis was also observed in carp, but to a much lesser extent than in trout (Purdom, C.E., 1994).

A study done by the Orlando was the first study to demonstrate the endocrine and reproductive systems of wild fish can be affected by feedlot effluent (FLE). Wild fathead minnows (*Pimephales promelas*) were exposed to FLE and observed significant alterations in their reproductive biology. Male fish were demasculinized (having lower testicular testosterone synthesis). Defeminization of females, as evidenced by a decreased estrogen:androgen ratio *(*Orlando, et.al., 2004). Similarly in another study, in Boulder, Colorado, the sex ratios of fish upstream from a wastewater treatment plant were 47% female to 53% male, while the ratios of those downstream from the plant were 83% female to 17% male. Researchers speculate this

disturbance could be associated with endocrine-disrupting compounds, including a synthetic estrogen, found in the treatment plant effluent (Woodling, et al., 2006).

Recently, ten wastewater treatment plants in Japan were surveyed for ecotoxicity tests of the pharmaceuticals and personal care products (PPCPs) and its concentration levels in wastewater. It was concluded that some antiseptic agents and antibiotics may cause adverse effects on aquatic ecosystems if gray water is not collected and treated, or if the dilution rate of the receiving river is low (Suzuki, et.al, 2007). According to another investigation done in UK to analyze, the current use of cytotoxic drugs could pose a risk to aquatic organisms and to humans through water recycling. The study predicts 5–50 ng/L concentrations for long stretches of the catchment under low flow conditions. All eukaryotic organisms are vulnerable to damage, with teratogenicity being the greatest concern at such levels (Johnso, et.al., 2008). In another study, the toxicity of oxytetracycline (OTC) was evaluated in adult grass shrimp, Palaemonetes pugio. A calculated lethal concentration 50% value of 683.30 mg/L OTC was determined from these tests with a lowest-observable effect concentration of 750 mg/L and no-observable-effect concentration of 500 mg/L (Uyaguari, et.al., 2009).

A national pilot study was initiated in USA to assess the accumulation of PPCP's in five dominating rivers that receive direct discharge from wastewater treatment facilities. Analysis of pharmaceuticals revealed the presence of norfluoxetine, sertraline, diphenhydramine, diltiazem, and carbamazepine. There was an additional presence of fluoxetine and gemfibrozil which was confirmed in liver tissue. Sertraline was detected at concentrations as high as 19 and 545 ng/g. More pharmaceuticals were detected at higher concentrations and with greater frequency in liver than in fillet tissues. (Ramirez, et.al., 2009). Another study to investigate the toxicity effects was done in 2009, to unearth the environmental effects from progestogenic hormones, a component in oral contraceptives. In order to test the effects of two progestins in contraceptive formulations, levonorgestrel (LNG) and drospirenone (DRSP), were investigated in adult fathead minnows (Pimephales

promelas). Both tested progestins caused an inhibition of reproduction. High concentrations resulted in masculinization of females (Zeilinger, et.al., 2009).

In recent times, very high levels of a range of pharmaceuticals have been reported in the effluent from a wastewater treatment plant near Hyderabad, India. To assess potential effects on aquatic vertebrates whether these levels are sufficiently high to adversely affect fish or amphibians, Tadpoles of Xenopus tropicalis were exposed to three dilutions of effluent (0.2, 0.6, and 2%) over 14 d and newly fertilized zebrafish (Danio rerio) were exposed to diluted effluent in 96-well plates for up to 144 h postfertilization (hpf). A 40% reduced growth of the exposed tadpoles was demonstrated at the lowest tested effluent concentration (0.2%), indicating potent constituents in the effluent that can adversely affect aquatic vertebrates. The median lethal concentration (LC50) for zebrafish at 144 hpf was between 2.7 and 8.1% in different experiments. Reduced spontaneous movements, pigmentation, and heart rate were recorded within 48 hpf at 8 and 16% effluent concentrations (Carlsson, et.al., 2009).

Recently a greenhouse experiment was done, to study the potential accumulation of the PPCPs into the plants, through biosolids and effluents from wastewater treatment. The uptake of three pharmaceuticals (carbamazepine, diphenhydramine, and fluoxetine) and two personal care products (triclosan and triclocarban) by an agriculturally important species, soybean plants were done. Growing for 60 and 110 days, Carbamazepine, triclosan, and triclocarban were found to be concentrated in root tissues and translocated into above ground parts including beans. TCS (16.9 ± 2.6 ng g-1) was detected with the highest concentration in root whereas CBZ (216 ±75 ng g-1) in leaf (Wu, c., 2010).

The Preliminary results of an ongoing current project, Emerging Contaminant Effects on Coastal Fish by the Southern California Coastal Water Research Project Authority, indicators of endocrine disruption. Unusually high estrogen concentrations in males, reduced thyroid hormone concentrations, and impaired production of the stress hormone cortisol (anonymous f, 2010).

2.5.3 Removal Methods

The presence of bioactive trace pollutants such as pharmaceuticals and ingredients of personal care products (PPCPs) in different environmental compartments (rivers, lakes, ground waters, sediments, etc.) is an emerging issue due to the lack of existing information about the potential impact associated with their occurrence, fate and ecotoxicological effects. Due to the low PPCP concentrations reported in wastewaters (ppb or ppt) and their complex chemical structure, common technologies used in sewage and drinking water treatment plants may not be efficient enough to accomplish their complete removal. (Suarez et al., 2008, Barcelo, 2010). Therefore, in order to ensure compliance with future discharge requirements, an upgrading of existing wastewater treatment facilities and implementation of new technologies for improvement of wastewater treatment many studies have been done.

According to a study the concentration of pharmaceuticals in effluent from conventional wastewater treatment plants is similar. Advanced wastewater treatment plants equipped with reverse osmosis systems reduce concentrations of pharmaceuticals below detection limits. In addition to removal during biological wastewater treatment, pharmaceuticals also are attenuated in engineered natural systems (i.e., treatment wetlands, ground water infiltration basins). Preliminary evidence suggests limited removal of pharmaceuticals in engineered treatment wetlands and nearly complete removal of pharmaceuticals during ground water infiltration (Sedlak and Karen, 2001).

To study the occurrence of trace organic contaminants in wastewaters, as their behavior during wastewater treatment and production of drinking water are key issues in the re-use of water resources. Researchers reviewed the state-of-the-art in the analysis of several groups of emerging contaminants (acidic pharmaceuticals, antibacterial agents, acidic pesticides and surfactant metabolites) in wastewaters. It also discusses the elimination of emerging contaminants in WWTPs applying conventional activated sludge treatment (AST) and advanced treatment processes, such as membrane bioreactors (MBRs) and advanced oxidation processes (AOPs), as well as during production of drinking water (Petrovi et al., 2003).

Recently a review was done (Xia, K. et al., 2005) on the basis of current available information on the occurrence of PPCPs in biosolids, methods of analysis, the potential fate of PPCPs in biosolids-applied soils, and composting as a potential means for removal of PPCPs from biosolids. They found the Biosolids can be a major sink for some PPCPs. To prevent PPCPs from entering the environment, there was an urgent need to document effective waste- water and biosolids treatment techniques. Composting can effectively remediate many xenobiotic organic contaminants and many other PPCPs in biosolids as well (Xia Kang, et.al , 2005).

According to a study, the removal of seven pharmaceuticals and two fragrances in the biological units of various full-scale municipal wastewater treatment plants was studied. The observed removal of pharmaceuticals was mainly due to biological transformation and varied from insignificant (<10%, carbamazepine) to>90% (ibuprofen). Overall, it can be concluded that for compounds showing a sorption coefficient (K_d) of below 300 L kg^{-1}, sorption onto secondary sludge is not relevant and their transformation can consequently be assessed simply by comparing influent and effluent concentrations (Joss et al., 2005).

A study investigated the removal of EDC/PPCPs of 52 compounds having different physico-chemical properties (e.g., size, hydrophobicity, and polarity) by nanofiltration (NF) and ultrafiltration (UF) membranes using a dead-end stirred-cell filtration system. EDC/PPCPs were applied to the membrane in one model water and three natural waters. The results showed that the NF membrane retained many EDC/PPCPs due to both hydrophobic adsorption and size exclusion, while the UF membrane retained typically hydrophobic EDC/PPCPs due mainly to hydrophobic adsorption (Yoon et al., 2005).

According to a study (Batt et al., 2007), the occurrence of ciprofloxacin, sulfamethoxazole, tetracycline, and trimethoprim antibiotics in four full-scale wastewater treatment plants (WWTPs) that differ in design and operating conditions was determined. The WWTPs chosen utilized a variety of secondary removal processes, such as a two stage activated sludge process with a nitrification tank, extended aeration, rotating biological contactors, and pure oxygen activated sludge.

Several of the WWTPs also employed an advanced treatment process, such as chlorination and UV radiation disinfection. Based on these four full-scale WWTPs evaluated, the apparent removal of organic micropollutants in wastewater is dependent on a combination of biological and physico-chemical treatment processes and operating conditions of the treatment system.

According to a study (Matamoros et al., 2007), Removal efficiencies and elimination kinetics of 13 pharmaceuticals and personal care products (PPCPs) and BOD_5, TSS, and ammonium were evaluated in a pilot vertical subsurface-flow constructed wetland (VFCW) and compared with those obtained by a sand filter. On the basis of the observed removals, the PPCPs studied were grouped in relation to their removal efficiency into (i) PPCPs very efficiently removed, that is, >95% removal in one of the systems (caffeine, salicylic acid, methyl dihydrojasmonate, CA-ibuprofen, hydrocinnamic acid, oxybenzone, ibuprofen, OH-ibuprofen); (ii) PPCPs moderately removed, with removals between 70 and 90% in the two systems (naproxen, diclofenac, galaxolide, and tonalide); and finally (iii) PPCPs poorly removed, with elimination rates of <30% (carbamazepine).

According to a recent study, treatment processes could be significantly, and relatively cheaply, improved to remove more harmful chemicals; natural & synthetic estrogens. These compounds can be destroyed by biochemical processes, albeit at significantly different rates or under different conditions. That is, estrogenic compounds can be, but are not always, destroyed by conventional wastewater treatment processes, suggesting that conventional processes can be optimized for removal of estrogenic activity from wastewater. Sorption to sludges derived from wastewater treatment affects the fates of hydrophobic xenoestrogens such as nonylphenol, in part because the biodegradability of sorbed contaminants is limited. It may also be possible to tailor sludge stabilization processes to remove trace contaminants, including estrogens (Teske and Robert, 2008).

Recently a study was done (Kim, and Hiroaki, 2009), The degradation characteristics of PPCPs commonly found in surface water under UV treatment were examined for 30 kinds of PPCPs, using a UV/Lamp1 that emits light at a wavelength

of 254 nm and a UV/Lamp2 that emits light at 254 nm and 185 nm in pure water. When a UV dose of some 230 mJ/cm^2 was introduced to the 30 PPCPs, photodegradation rates of about > 3% (theophylline) to 100% (diclofenac) and about > 15% (clarithromycin) to 100% (diclofenac) were observed for UV/Lamp1 and UV/Lamp2, respectively. This study showed that UV/Lamp2, which photolyzes water molecules and generates OH radicals, is more effective for PPCP removal than UV/lamp1.

According to a review study (Suarez et al., 2009), some PPCPs are very well eliminated by conventional sewage treatment configurations, new strategies such as modification of operating conditions (e.g. solids retention time), implementation of new technologies (e.g. biomembrane reactors) or additional advanced post-treatment steps (e.g. oxidation, adsorption, membranes) have been suggested for an increased efficiency.

A study was done in order to assess the efficiency of wastewater treatment plants in removing pharmaceuticals from wastewater. Conventional activated sludge (CAS) and membrane bioreactor (MBR) treatment systems are compared in eliminating pharmaceuticals in wastewater. In the influent, the concentration of the compounds ranges from 0.09 to 1.4 μg/L. Diclofenac shows resistance to degradation in the CAS but is amenable to degradation in the MBR. Trimethoprim and enalapril are only slightly eliminated in the CAS but are reduced by more than 95% in the MBR. Carbamazepine removal is negligible, while aceclofenac is only 50% reduced in CAS and MBR. In general, these results indicate that MBR has a higher efficiency in removing some polar pharmaceuticals in wastewater (Celiz et al., 2009).

A recent study focus on the removal of PPCPs during conventional (e.g., activated sludge) and advanced (e.g., ozonation and membrane filtration) treatment processes. It compiles nearly 1500 data from over 40 published sources pertaining to influent and effluent PPCP concentrations measured at pilot- and full-scale wastewater treatment facilities to identify the most effective series of technologies for minimizing effluent PPCP levels. Available data suggest that at best 1-log10 concentration unit (90%) of PPCP removal can be achieved at plants employing only primary and

secondary treatment, a performance trend that is maintained over the range of reported PPCP influent concentrations (~0.1- 10^5 ng/L). Relatively few compounds (15 of 140 PPCPs considered) are consistently removed beyond this threshold at facilities using solids removal and conventional activated sludge (CAS), and most PPCPs are removed to a far lesser extent. Passive approaches for tertiary treatment (e.g., wetlands and lagoons) represent promising options for PPCP removal (Oulton, et.al, 2010).

2.5.4 Analytical Techniques

In 1987, the Organic Geochemistry Research Group was established at the U.S. Geological Survey (USGS) in Lawrence, Kansas, to investigate the fate, degradation, and transport of agricultural chemicals in surface water, ground water, and precipitation. Since that time, the goals of the research group have been expanded to include: (1) the development of analytical methods, (2) investigation of the occurrence, concentration, and movement of herbicides, insecticides, antibiotics, taste-and-odor-causing compounds, and degradation products in surface water, ground water, and precipitation throughout the United States, and (3) study of the degradation, transport, and fate of agricultural chemicals in the hydrologic system (Scribner, 2001).

A method was developed for the trace analysis of two classes of antimicrobials consisting of six sulfonamides (SAs) and five tetracyclines (TCs), which commonly are used for veterinary purposes and agricultural feed additives and are suspected to leach into ground and surface water. The method used solid-phase extraction and liquid chromatography/mass spectrometry (LC/MS) with positive ion electrospray. The unique combination of a metal chelation agent (Na_2EDTA) with a macroporous copolymer resulted in quantitative recoveries by solid-phase extraction at submicrogram-per-liter concentrations. Unusual matrix effects were seen only for TCs in this first survey of groundwater and surface water samples from sites around the United States, requiring that TCs be quantitated using the method of standard additions (Lindsey, 2001).

An experimental study was conducted to investigate the removal of EDC/PPCPs of 52 compounds at environmentally relevant initial EDC/PPCP. EDC/PPCP retention was quantified by liquid and gas chromatography with mass spectroscopy–mass spectroscopy (Yoon et al., 2005).

In an another study, the researchers investigated the occurrence of quinolone antibiotics (QAs) in wastewater effluents and surface river/lake waters in the US and Canada by using solid-phase extraction with mixed phase cation exchange disk cartridge and liquid chromatography– mass spectrometry (LC–MS) and liquid chromatography fluorescence detection (LC-FLD) (Haruhiko, et.al, 2005).

A study was carried out to understand the hazards of trace levels of PPCPs in water supplies to the environment and human health. A multi compound method using solid phase extraction and chemical derivatization with pentafluorobenzylbromide, followed by analysis via gas chromatography/mass spectrometry was used to study the occurrence and removals of 18 PPCPs in a local wastewater treatment plant (WWTP) (Yu et al., 2006).

Recently, a new multi-residue method using ultra-performance liquid chromatography (UPLC) quadrupole-time-of-flight mass spectrometry (Q–TOF–MS) was developed for screening and confirmation of 29 pharmaceutical compounds belonging to different therapeutical classes: analgesics and antiinflammatories, lipid regulating agents, cholesterol lowering statin agents, psychiatric drugs, anti ulcer agents, histamine H2 receptor antagonist, antibiotics and beta-blockers.

A recent study discusses (Pietrogrande et al., 2007) the more recent methods combining gas chromatography and mass spectrometry (GC-MS) for analysis of personal-care products (PCPs) in water matrices. They describe different procedures for sample extraction and preparation as well as different instrumental methods commonly used for these compounds. GC-MS and GC-tandem MS (GC-MS^2), which are complementary to liquid chromatography combined with MS (LC-MS), allow identification and quantification of PCPs belonging to different classes with the sensitivity and the selectivity necessary for environmental monitoring.

A study was done in South Korea at 5 Sites along the Mankyung River. Collected Samples were tested using a liquid chromatograph coupled with a tandem mass spectrometer (LC/MS/MS) for 13 PPCPs. Overall, 11 out of the 13 selected PPCPs, which span a range of therapeutic classes and one personal care product, were detected in surface water samples collected from the Mankyung River (Joon-Woo Kim, et.al , 2009).

According to a study, occurrence of 66 PPCPs (pharmaceuticals and personal care products) in liquid and solid phases of sewage sludge was elucidated. The extraction methods for the PPCPs from sludge were newly developed employing Pressurized Liquid Extraction (PLE) and Ultrasonic Solvent Extraction (USE). As an appropriate method, PLE using water (pH2), PLE using methanol (pH4), and USE using mixture of methanol and water (1/9,v/v, pH11) was found most effective because total recovery of most of the PPCPs indicated 40 to 130%. The developed extraction method with previously developed method for liquid phase analysis LC/MS/MS was applied to field survey at wastewater treatment plants (WWTPs) in Japan (Okuda et al., 2009).

A study was done (Celiz et al., 2009) in order to assess the efficiency of wastewater treatment plants in removing pharmaceuticals from wastewater, sensitive and reliable methods are necessary for trace analysis of these micro pollutants in the presence of a highly complex matrix. Analysis is performed using a liquid chromatography with hybrid linear ion-trap mass spectrometer equipped with a polar reversed-phase column to achieve good separation and minimize matrix effects. To preconcentrate the samples, the use of two types of solid-phase extraction packing materials in tandem assures good recoveries of all the target analytes.

To summarize, the analytical techniques used for PPCPs over the past 2 decades include:

(1) Gas Chromatography/Mass Spectrometry (GC/MS)

(2) Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS)

(3) High Performance Liquid Chromatography/Tandem Mass Spectrometry (HPLC/MS/MS)

(4) Ultra Performance Liquid Chromatography quadrupole-time-of-flight mass spectrometry (UPLC /Q–TOF–MS)

For the present study HPLC/MS/MS would be used for the analyses.

The comparative review of some of the past studies on PPCPs is summarized in Table 2.1

Table 2.1 The comparative review of some of the past studies on PPCPs

Date	**Authors**	**Title**	**Summary of the work**
1998	Thomas A. Ternes	Occurrence of Drugs in German Sewage Treatment Plants and Rivers	Results showed that <80% of the selected drugs were detectable in at least one municipal STP effluent with concentration levels up to 6.3 µg/L (carbamazepine) and thus resulting in the contamination of the receiving waters. Mainly acidic drugs and neutral or weak basic drugs were found to be ubiquitously present in the rivers and streams, mostly in the ng/L range. However, maximum concentrations were determined up to 3.1 µg/L and median values as high as 0.35 µg/L (both bezafibrate).

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2002	D.W. Kolpin, E D Ward T. Furlong, M. T. Meyer, M. L Thurman, S. D. Zaugg, L. B. Barber, H. T. Buxton	Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance	The compounds detected in many US streams represent a wide range of residential, industrial, and agricultural origins and uses with 82 of the 95 OWCs being found. The most frequently detected compounds were coprostanol (fecal steroid), cholesterol (plant and animal steroid), N,N-diethyltoluamide (insect repellant), caffeine (stimulant), triclosan (antimicrobial disinfectant), tri(2-chloroethyl)phosphate (fire retardant), and 4-nonylphenol (nonionic detergent metabolite), generally at low levels.
2002	X. S. Miao, Brenda G. Koenig, Chris D. Metcalfe	Analysis of acidic drugs in the effluents of sewage treatment plants using liquid chromatography–electrospray ionization tandem mass spectrometry	Results indicated that the mean recoveries of the nine acidic pharmaceuticals ranged from 58.9 to 91.5% in STP effluent, and the limits of detection of the analytes were 5–20 ng/ml. The method was applied to the quantitative analysis of acidic drugs in the effluents from three Canadian STPs.

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2003	Boyd, G.; H. Reemtsma; D. Grim; and S. Mitra	Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada	Naproxen and Triclosan was detected in Louisiana STP effluent at 81–106 ng/L and 10–21 ng/L, resp. Louisiana and Ontario surface waters at 22–107 ng/L. Clofibric acid was detected in Detroit River at 103 ng/L. Results showed - various stages of treatment, conventional drinking-water treatment processes (coagulation, flocculation and sedimentation) plus continuous addition of powdered activated carbon at a dosage of 2 mg/L did not remove naproxen.
2004	Carballa, M; F. Omil; JM Lema; M Llompart; C Garcia-Jares; I Rodriguez; M Gomez; T Ternes	Behavior of pharmaceuticals, cosmetics and hormones in a sewage treatment plant	The overall removal efficiencies within the STP ranged between 70-90% for fragrances, 40-65% for anti-inflammatory, around 65% for 17b-estradiol, and 60% for sulfamethoxazole. The concentration of estrone increased along the treatment due to partial oxidation of 17b-estradiol in the aeration tank.
2005	Clara, M.; B. Strenn; O. Gans; E. Martinez; N. Kreuzinger; and H. Kroiss	Removal of selected pharmaceuticals, fragrances and EDCs in a membrane bioreactor and conventional WWTPs	Results showed that Carbamazepine was not removed in any of the sampled treatment facilities. BPA, ibuprofen, and bezafibrate were nearly completely removed (>90%). SRTs suitable for nitrogen removals (SRT > 10 days) increase the removal of selected micropollutants. NP/APEs were removed in high extend in very low-loaded conventional WWTPs.

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2006	Sara Castiglioni, Renzo Bagnati, Roberto Fanelli, Francesco Pomati, Davide Calamari, Ettore Zuccato	Removal of Pharmaceuticals in Sewage Treatment Plants in Italy	Results showed that total loads ranged from 1.5 to 4.5 g/day/1000 inhabitants in influents and 1.0 and 3.0 g/day/1000 inhabitants in effluents. Total removal rate (RR) in STPs were mostly lower than 40%. Pharmaceuticals could be divided into 3 groups according to their behavior in STPs: one group with RR higher in summer than in winter, one group with RR similar in summer and winter, and a last group not removed.
2007	Gobel, Anke; Christa S. McArdell; Adriano Joss; Hansruedi Siegrist; Walter Giger	Fate of Sulfonamides, Macrolides, and Trimethoprim in Different Wastewater Treatment Technologies	Primary treatment provided no significant removal and secondary treatment observed for two CAS systems and a fixed bed reactor showed little to no removal. The removal for macrolides and trimethoprim varied significantly between the different sampling campaigns in the two CAS systems and in the FBR. In the MBR, analytes were removed up to 50% at SRT of 16±2 and 33±3 d. Trimethoprim, clarithromycin and dehydro-erythromycin showed a higher removal of up to 90% at a SRT of 60–80 d indicating a correlation with reduced substrate loading (SL). A significant removal of most macrolides (17–23%) and trimethoprim (74±14%), while no removal was observed in the other sand filter investigated.

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2007	Carballa, Marta; Fransesco Omil; Juan M. Lema	Calculation methods to perform mass balances of micropollutants in sewage treatment plants. Application to pharmaceutical personal care products (PPCPs)	Two methods (calculated data and measured data) are used to perform mass balance calculations to determine the mechanism of removal. Ibuprofen, naproxen, and sulfamethoxazole are biologically degraded in the aeration tank (50-70%), while musks are equally sorbed to the sludge and degraded. In contrast, estrogens are not removed in the STP studied. About 40% of the initial load of pharmaceuticals passes through the plant unaltered, with the fraction associated to sludge lower than 0.5%. Estrogens were not removed by the STP.
2008	Kyungho Choi, Y. Kim, J. Jung, M.H. Kim, Chang-Soo Kim, Nam-Hee Kim, Jeongim Park	Occurrences and ecological risks of roxithromycin, trimethoprim, and chloramphenicol in the Han River, Korea	The levels for trimethoprim and chloramphenicol, in surface water during low flow were, on average, 108 and 31 ng/L, respectively. These levels were comparable to those measured in the municipal effluents (average, 80 and 37 ng/L, respectively). Roxithromycin in surface water, levels were approximately an order of magnitude lower than effluent levels. Adverse effects of roxithromycin, trimethoprim, and chloramphenicol were observed at mg/L levels.

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2008	Jeff Donn, Martha Mendoza and Justin Pritchard, Associated Press	AP: Drugs found in drinking water	An Associated Press investigation shows that Pharmaceuticals — including antibiotics, anti-convulsants, mood stabilizers and sex hormones — were found in the drinking water supplies of at least 41 million Americans. Tests were conducted in the 35 watersheds of the 62 major providers surveyed by the AP, and pharmaceuticals were detected in 28 of them.
2009	Jerker Fick, Hanna Soderstrom, Richard H. Lindberg, Chau Phan, Mats Tysklind, and D.G. Joakim Larsson	Contamination Of Surface, Ground, And Drinking Water From Pharmaceutical Production	Results showed that Very high concentrations of ciprofloxacin (14 mg/L) and cetirizine (2.1 mg/L) were found together with high concentrations of seven additional pharmaceuticals. Surface water was analyzed from the recipient stream and from two lakes that are not contaminated by the treatment plant -Very high concentrations of ciprofloxacin (up to 6.5 mg/L), cetirizine (up to 1.2 mg/L), norfloxacin (up to 0.52 mg/L), and enoxacin (up to 0.16 mg/L) were also detected in the two lakes. Water samples taken from wells in six nearby villages were determined to be contaminated with drugs - Ciprofloxacin, enoxacin, cetirizine, terbinafine, and citalopram were detected at more than 1 mg/L in several wells.

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2009	Ying, Guang-Gou; Rai Kookana; Anu Kumar	Fate of estrogens and xenoestrogens in four sewage treatment plants with different technologies	The concentrations of 8 compounds in the effluents from the 15 STPs showed substantial variations among the STPs, with their median concentrations ranging from 26 ng/L for caffeine to 710 ng/L for carbamazepine. Risk assessment from the present study suggested potential toxic risks to aquatic organisms posed by carbamazepine, triclosan and diclofenac associated with such effluent discharge. On average, CAS and oxidation ditch treatments removed estrogenic compounds better than lagoons and bioreactors.
2010	Li Wang, Guang-Guo Ying, Jian-Liang Zhao, Xiao-Bing Yang, Feng Chen, Ran Tao, Shan Liu, Li-Jun Zhou	Occurrence and risk assessment of acidic pharmaceuticals in the Yellow River, Hai River and Liao River of north China	Results indicated that 7 acidic compounds were detected in the rivers. Acidic pharmaceuticals' concentrations in the Yellow River and Liao River were (most cases) - higher in the dry season than in the wet season, but the concentrations of acidic compounds in the Hai River - generally higher in July than in November. High concentrations - in the Yellow River, Hai River and Liao River were found more frequently at - metropolitan areas, lower reaches or river confluences. Diclofenac and ibuprofen were found - medium to high risks in the three rivers based on the HQs

Table 2.1 The comparative review of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2010	S. Hyun Koo, Cheon Ho Jo, Sun Kyoung Shin, and Seung-Woon Myung	Simultaneous Determination and Occurrences of Pharmaceuticals by Solid-Phase Extraction and Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) in Environmental Aqueous Samples	Results indicated that the limits of detection (LOD) in distilled water and the blank surface water were in the range of 0.006 - 0.65 and 1.66 - 45.05 pg/mL, resp. The LOQ for the distilled water and the blank surface water were in the range of 0.02 - 2.17 and 5.52 - 150.15 pg/mL, resp. The absolute recoveries for fortified water samples were between 62.1% and 125.4%. In surface wastewater near rivers, chlortetracycline and acetylsalicylic acid were detected in the range of 0.017 - 5.404 and 0.029 - 0.269 ng/mL, resp.
2011	T. H. Yu, A. Y.C. Lin, Sri Chandana Panchangam, Pui-Kwan Andy Hong, Ping-Yi Yang, Cheng-Fang Lin	Biodegradation and bio-sorption of antibiotics and non-steroidal anti-inflammatory drugs using immobilized cell process	In this study, biodegradation and bio-sorption were found as dominant mechanisms for the drug removal, while volatilization and hydrolysis were negligible. The pharmaceuticals responded to the two removal mechanisms in different ways, typically: (1) strong biodegradability and bio-sorption by acetaminophen, (2) strong biodegradability and weak bio-sorption by sulfamethoxazole, sulfadimethoxine, ibuprofen and naproxen, (3) low biodegradability and weak bio-sorption by sulfamethazine and ketoprofen, and (4) low biodegradability and medium bio-sorption by trimethoprim.

Table 2.1 The comparative review of some of past studies on PPCPs (continued)

Date	Authors	Title	Summary of the work
2011	Qian Sui, Jun Huang, Shubo Deng, Weiwei Chen, and Gang Yu	Seasonal Variation in the Occurrence and Removal of Pharmaceuticals and Personal Care Products in Different Biological Wastewater Treatment Processes	Seasonal variations of PPCPs in the wastewater influent were discrepant, while in the wastewater effluent, most PPCPs had lower concentrations in the summer than in the winter. For the easily biodegradable PPCPs, the performance of MBR was verified to be more stable than CAS or BNR especially during winter months. Diclofenac, trimethoprim, metoprolol, and gem fibrozil could be moderately removed by MBR, while their removal by CAS and BNR was much lower or even negligible.
2012	Ying Li, Ranjna Jindal , Kyungho Choi, Young Lim Kho, Pura Garcia de Bullen	Pharmaceutical Residues in Wastewater Treatment Plants and Surface Waters in Bangkok (Thailand)	The results indicated that levels of pharmaceutical residues in the influents on an average were - caffeine (9,052 ng/L), acetaminophen (8,630 ng/L) and roxithromycin (235 ng/L). The top three levels in the effluents - caffeine: 797 ng/L, acetaminophen: 92 ng/L and roxithromycin: 50 ng/L). In downstream surface water samples higher concentrations were - caffeine (2,393.4 ng/L), acetaminophen (839.3 ng/L) and roxithromycin (54.7 ng/L)

CHAPTER III
MATERIALS AND METHODS

3.1. Site Selection and Sampling

In this study, investigations were carried out in two Asian cities- Bangkok, Thailand, and Seoul, South Korea. The details of sampling sites are presented in following sections.

3.1.1 Site Selection and Sampling Points in Bangkok

Five wastewater treatment plants (WWTPs) and the regions of their outfalls into six canals and the Chao Phraya River were chosen as the study area in Bangkok, Thailand (Figure 3.1).

Selection of Wastewater Treatment Plants (WWTPs)

At present, there are total of seven municipal wastewater treatment plants in and around Bangkok, Thailand. Five full-scale WWTPs were selected for this study: Si Phraya (SP), Rattanakosin (RK), Chong Nonsi (CN), Din Daeng (DD) and Thung Kru (TK). The criteria for selection of these WWTPs were based on following points:

- All five WWTPs adjacent to Chao Phraya River were selected for sampling with the view that these could be most likely responsible for polluting the river water.
- All five WWTPs employ different biological treatment processes; therefore it would be possible to evaluate the effect of treatment method on removal of pharmaceuticals.

The basic information, characteristics and operating conditions of WWTPs are presented in Table 3.1. Locations and the service areas covered by the WWTPs are shown in Fig 3.1.

Table 3.1: Details of five selected WWTPs in Bangkok, Thailand

WWTPs→	Si Phraya (SP)		RattanaKosin (RK)		ChongNonsi (CN)		Din Daeng (DD)		Thung Khru (TK)	
Capacity (m^3/d)	30,000		40,000		200,000		350,000		65,000	
Population served	120,000		76,000		580,000		1,080,000		177,000	
Service Area (km^2)	2.70		4.14		28.50		37.00		42.00	
Treatment Process	Contact Stabilization A.S.		Two- Stage A.S.		Cyclic A.S.		A. S. with Nutrients Removal		Vertical Loop Reactor A.S.	
Downstream Receiving Water Body	Klong Phadung Krunkasem (KPK)		Klong Banglampoo (KBP)		Chao Phraya River		Klong Sam Sen (KSS)		Klong Bang Jak (KBJ)	
Parameter	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
BOD_5 (mg/L)	53.3	5.4	72	13.7	31.5	5.6	35.3	10.2	44.3	4.7
SS (mg/L)	75	6	-	-	47.5	11.3	60.8	11.5	76	7.6
TP (mg/L)	1.4	1.2	2.6	1.4	2.4	1.5	2.3	1.4	2	0.8
TKN (mg/L)	10.5	1.7	6.2	3.1	9.9	1.9	14.5	4.6	10.9	1.8
TN (mg/L)	12.7	8.6	6.7	6.4	10.5	6.1	14.1	8.6	12.4	7.7
pH	7.3	6.5	6.8	6.8	7.3	7.4	7.2	7.1	7.6	7.9
DO (mg/L)	-	3.1	-	6	-	6.5	-	6.6	-	6.4

Note: Transient population was not included in the population served data, A.S. = Activated sludge process, Inf. = Influents, Eff. = Effluents, BOD = biochemical oxygen demand, COD = chemical oxygen demand, SS = suspended solids, TP = total phosphorus, TKN = total kjeldahl nitrogen, TN = total nitrogen, DO = dissolved oxygen

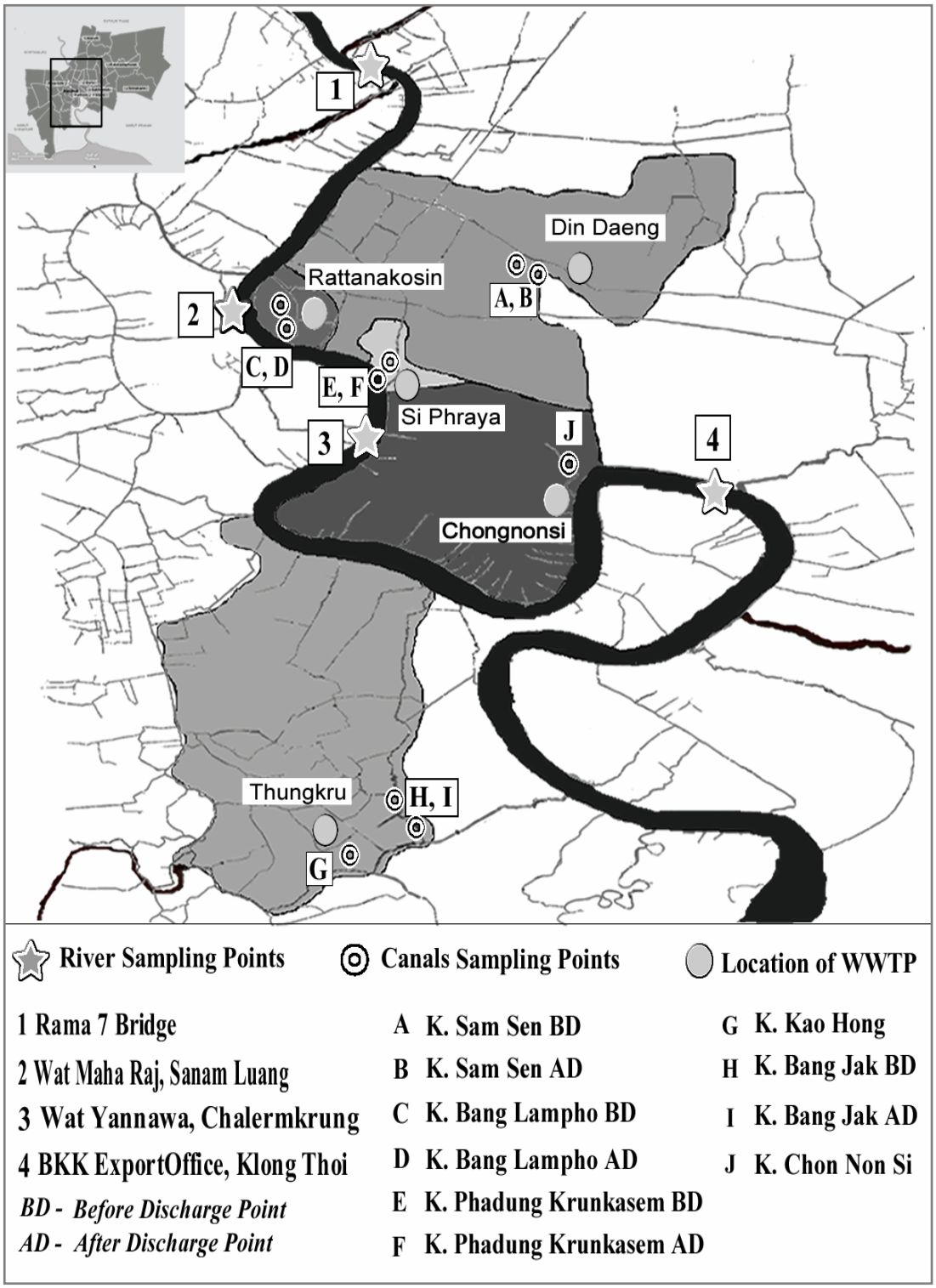

Fig. 3.1 Sampling points in Bangkok, Thailand
Note: sampling points for river are: 1 - 4 and from canals: A – J

Sampling Points in WWTPs

The schematic diagrams of these treatment plants and the various sampling points are shown in Fig. 3.2. Mid- process points were selected in all WWTPs from the approximate center of process length and hydraulic retention time (HRT).

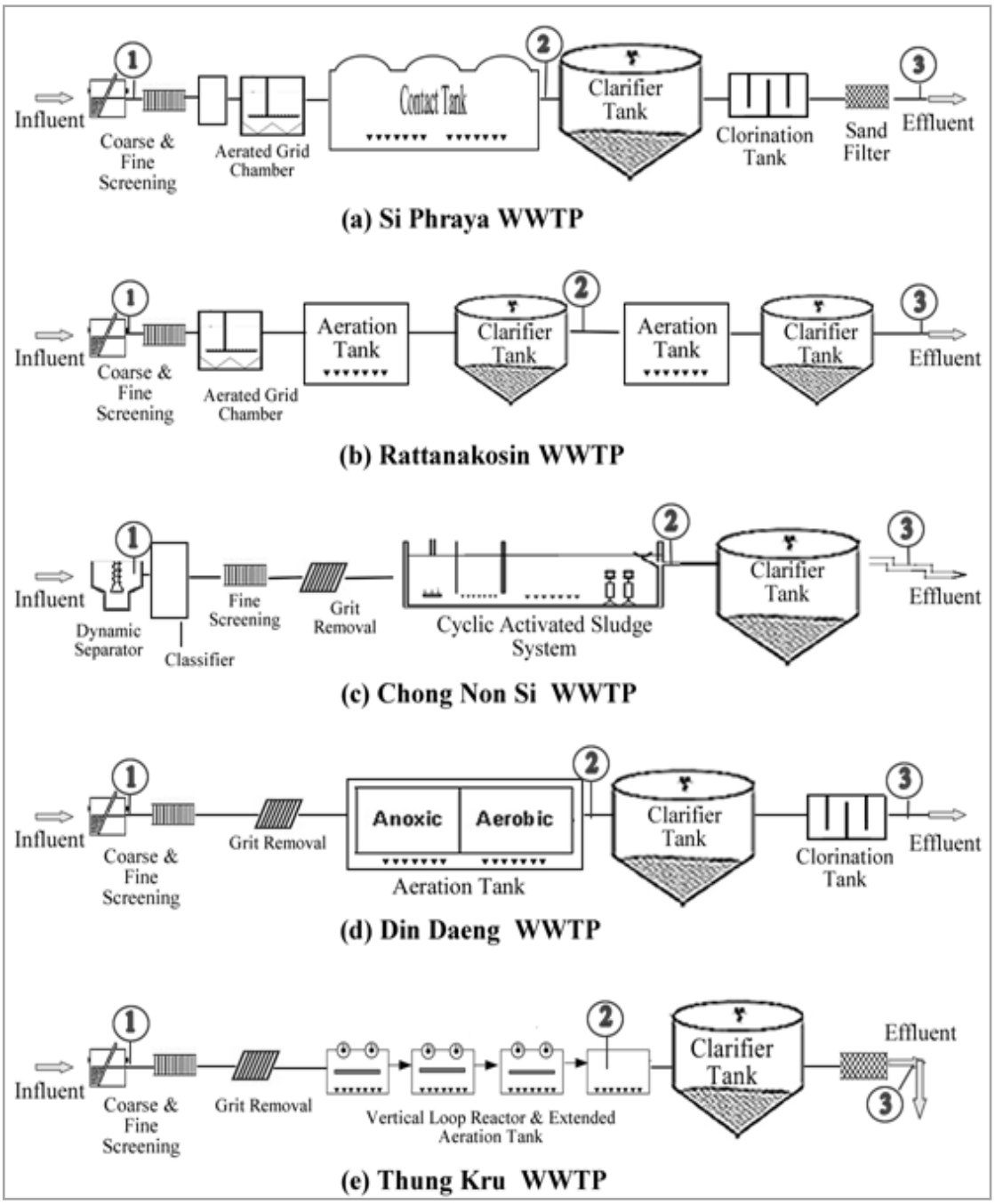

Fig. 3.2 Schematic diagrams of all five WWTPs and the sampling points, 1- Influent Point, 2- Mid-process Point, 3- Effluent Point

The **Si Phraya WWTP (SP)** receives wastewater from the Bangrake, Phimpharb, Wat Thepsirin and Khet Samphanthawong areas of Bangkok. This plant employs contact stabilization activated sludge process. The treatment scheme includes primary treatment - bar screen, automatic fine screen, equalization tank and aerated grit chamber, and secondary treatment - contact tank, clarifier tank, chlorine contact tank and sand filter. Samples from the mid-process point were taken from effluent of contact tank. Locations of sampling points for influent, mid-process and effluent are shown in Fig 3.3.

Fig 3.3 Sampling Points of Si Phraya WWTP (SP)

The **Rattanakosin WWTP (RK),** situated in the central part of Bangkok, is one of the first sewage collection and treatment plant setup by the Bangkok Metropolitan Administration (BMA). This plant is designed as a two-stage activated sludge process including primary treatment - coarse screening, fine screening, grit removal, and secondary treatment – 1st high rate aeration tank, 1st clarifier tank and 2nd extended aeration tank (to remove nitrogen), 2nd clarifier tank and chlorination tank. Samples of mid-process were taken from effluent of first clarifier tank. Locations of sampling points for influent, mid-process and effluent are shown in Fig 3.4.

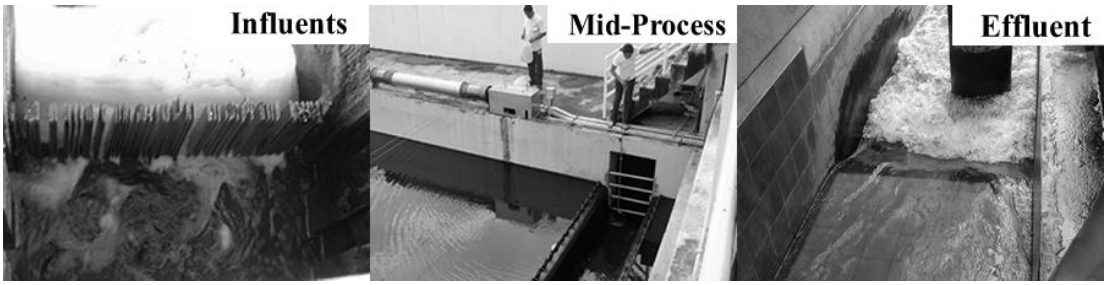

Fig 3.4 Sampling Points of Rattana Kosin WWTP (RK)

ChongNon Si WWTP (CN), situated in the southern part of Bangkok, employs cyclic activated sludge system (CASS) for treatment of wastewater for removal of specific target nutrients. The process scheme includes primary treatment - dynamic separator, classifier, fine screening, grit removal (vertex method), and secondary treatment - CASS, settling tank, and outfall cascade discharge (to enhance dissolved oxygen of effluent). The samples of middle point were taken from effluent of CASS. Locations of sampling points for influent, mid-process and effluent are shown in Fig 3.5.

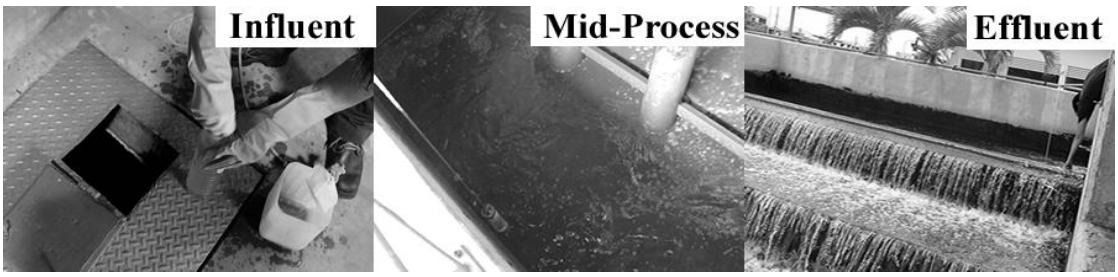

Fig 3.5 Sampling Points of ChongNon Si WWTP **(CN)**

Din Daeng WWTP (DD), situated in the northern area of Bangkok, is one of the biggest treatment plants in Thailand and neighboring countries. This plant is designed as activated sludge process and operates in anoxic and aerobic conditions to remove nitrogen and phosphorus from the WW. The treatment scheme includes primary treatment - coarse screening, fine screening, and grit removal, and secondary treatment - phosphorous removal tank, eight aeration tanks, clarifier tank and chlorination. The mid-point samples were taken from effluent of aeration tank. Locations of sampling points for influent, mid-process and effluent are shown in Fig 3.6.

Fig 3.6 Sampling Points of Din Daeng WWTP (DD)

Thung Kru WWTP (TK), situated in the south western part of Bangkok - on the other side of Chao Phraya River, employs vertical loop reactors (Envirex). This technique has many advantages, such as the capability to remove nutrients via an oxidation ditch in each reactor, low space requirements and low biosolids production (Metcalf and Eddy, 2003). The treatment scheme includes primary treatment - trash rack screening, fine screening, grit removal, and the secondary treatments - three vertical loop reactors, extended aeration tank, sedimentation tank and post aeration discharge of effluent (to enhance DO). Mid-process samples were taken from the 4th aeration tank. Locations of sampling points for influent, mid-process and effluent are shown in Fig 3.7.

Fig 3.7 Sampling points of Thung Kru WWTP (TK)

Sampling Points in Six Canals

Samples were collected from the six different canals: Klong Bang Lampho (KBL), Klong Phadung Krunkasem (KPK), Klong Sam Sen (KSS), Klong Bang Chak (KBJ), Klong Kao Hong (KKH) and Klong ChonNon Si (KCN) (Fig 3.1). Canals of KBL, KPK, KSS and KBJ receive the effluents from WWTPs of RK, SP, DD and TK, respectively. Samples were taken 10-15 m upstream (before discharge, i.e., BD) and downstream (after discharge, i.e., AD) of each WWTP outfall. The remaining canals of KKH and KCN do not receive the effluents from the above WWTPs, and were sampled from the point before the intersection with another canal or river. Locations of sampling points are shown in Fig 3.8.

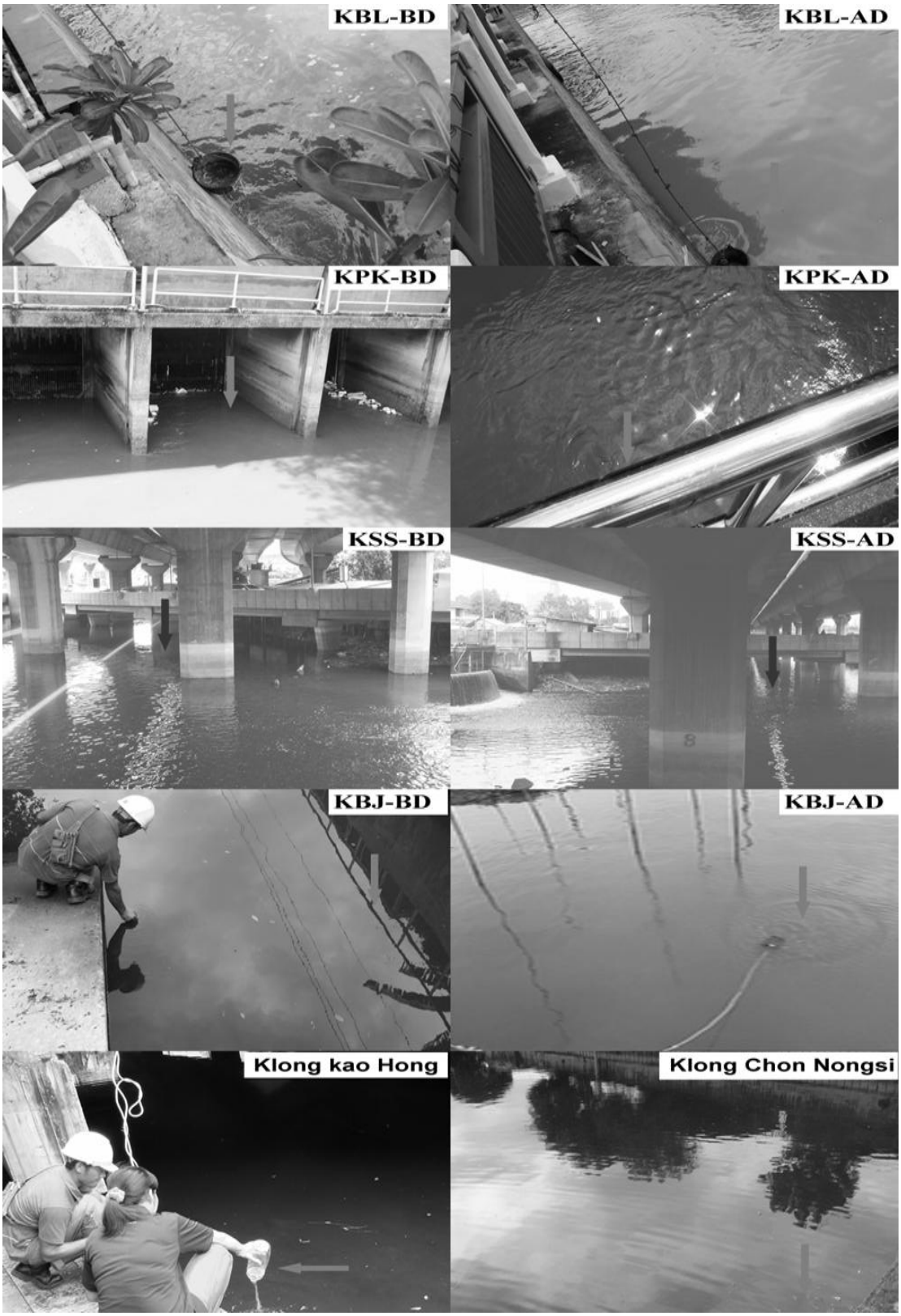

Fig 3.8 Sampling Points in six canals in Bangkok, Thailand

Sampling Points in Chao Phraya River

Chao Phraya River is one of the major rivers in Thailand. Its total length is 372 km and on average, it discharges 718 m^3/s water in Gulf of Thailand. Chao Phraya River is the secondary receiving water body for all WWTPs except for CN that directly discharges into it. Ambient water samples were collected from four locations in Chao Phraya River, i.e., Rama Seven Bridge (1-R7B), Wat Maha Raj at Sanam Luang (2-SL), Wat Yannawa at Chalerm Krung (3-CK) and Bangkok Export Office at Klong Toey (4-KT) (Fig 3.1). The first point - Rama 7 Bridge (1-R7B) was selected around the starting of Bangkok city, and the last point - Export office, Klong Toei (4-KT) was selected at just before the end of city boundary. Other two points - Mahraja Bridge (2-SL) and Wat Yannawa (3-CK), were selected between the first and last sampling points. Locations of sampling points are shown in Fig 3.9.

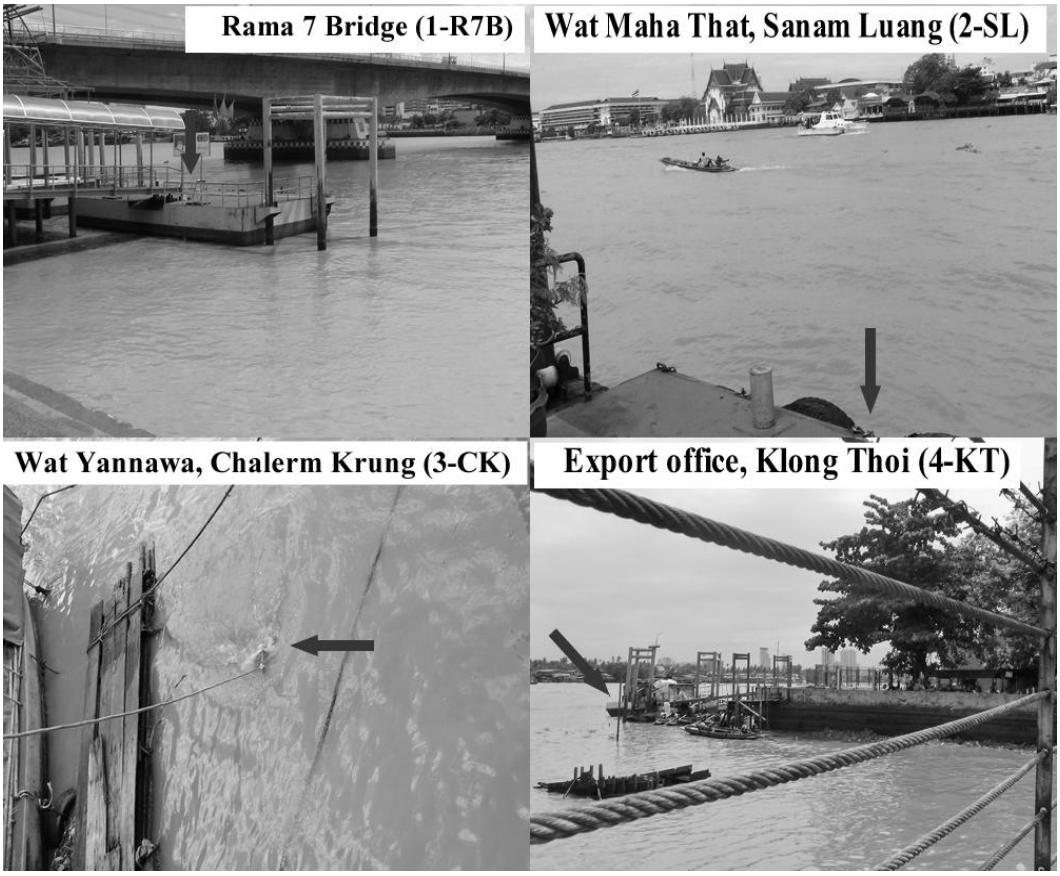

Fig 3.9 Sampling points in Chao Phraya River

3.1.2 Site Selection and Sampling Sites in Seoul, South Korea

There are four municipal sewage treatment plants (STPs) within the Seoul city boundary, i.e., JungRang (JR), TanCheon (TC), NanJi (NJ), and SeoNam (SN). All the four STPs discharge their effluents in to the main stream Han River. Characteristics of STPs are shown in Table 3.2. Han River is one of the major rivers in South Korea. Its total length is 514 km and on average, it discharges 670 m^3/s water in Yellow Sea. Samples from the Han River were collected at four locations: JamSil Bridge (JSB), HanNam Bridge (HNB), MaPo Bridge (MPB), and BangHwa Bridge (BHB). Locations of sampling points are shown in Fig 3.10

Table 3.2 Details of STPs in Seoul, South Korea

STPs →	**TanCheon**	**Jung Nang**	**NanJi**	**SeoNam**
Capacity (m^3/d)	903,956	1,525,142	890,329	1,714,034
Population served	1,720,000	2,798,000	1,795,000	3,363,000
Downstream Receiving Waters	Han River	Han River	Han River	Han River

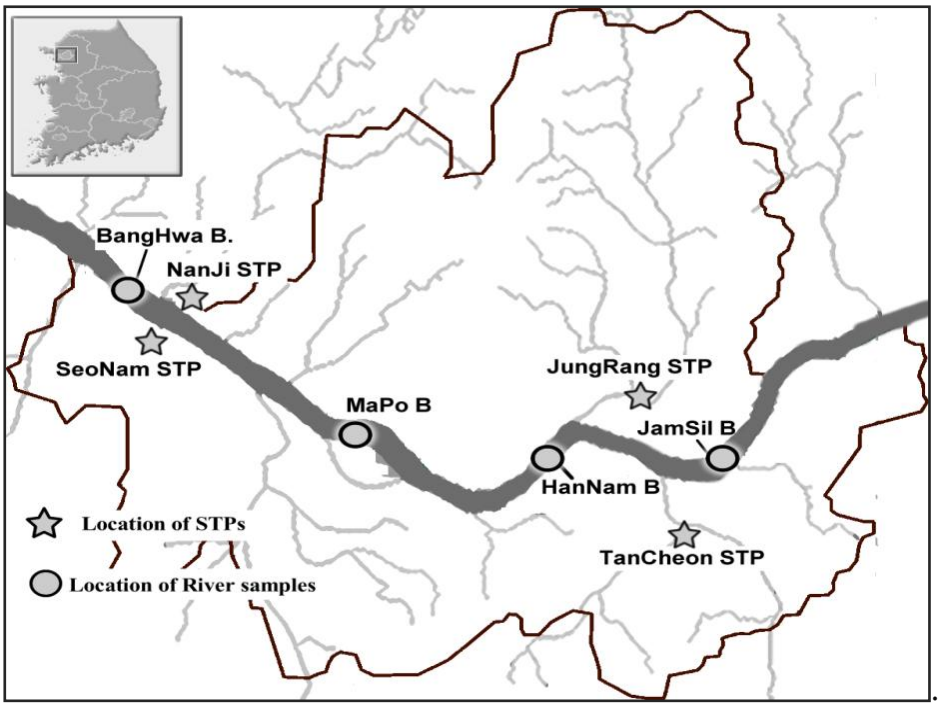

Fig 3.10 Sampling points in STPs and Han River in Seoul,South Korea

Sampling Points in STPs

The schematic diagrams of all four treatment plants are similar to each other, and the various sampling points are shown in Fig. 3.11. Mid- process points were selected in all WWTPs from the aeration tank.

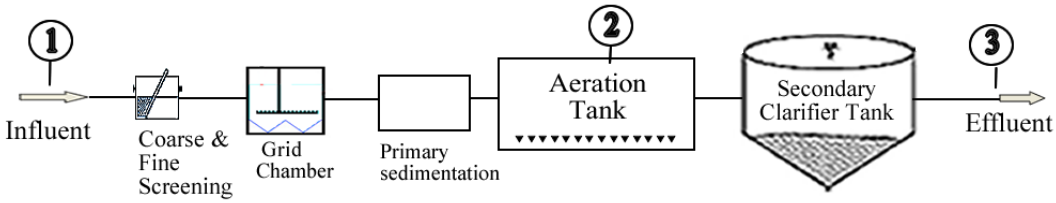

Fig. 3.11 Schematic diagram of STPs in Seoul, South Korea and the sampling points, 1- Influent Point, 2- Mid-process Point, 3- Effluent Point

3.1.3 Sample Collection

Grab samples were collected in four separate events (March 2011 in Seoul; June 2011, September 2011, and January 2012 in Bangkok). Plastic bottles (1.5 L) were used for sampling that were pre-rinsed several times in the laboratory with DI water, methanol and Milli-Q water, and rinsed again with ambient water on site. Samples were immediately placed on ice and brought to the laboratory within 8 h and were stored in a cold room (4^{o}C) until analysis. Analyses were carried out within a week after the sampling.

3.2 Target Compounds

Twenty three pharmaceuticals were selected for this study based on their frequent occurrences in WWTP effluents and receiving waters in some countries as reported in literature review (Choi et al., 2008,). The selected pharmaceuticals were from four main medicine groups:

(1) different types of antibiotics and antimicrobials
(2) acidic drugs / non-steroidal anti-inflammatory drugs (NSAIDs)
(3) beta blockers
(4) stimulants

Among the selected test pharmaceuticals, six were from acidic/non steroidal anti inflammatory drugs (NSAIDs): acetaminophen, acetylsalicylic acid, diclofenac, mefenamic acid, naproxen and ibuprofen; a commonly used medicine for treating non inflammatory pain. Fifteen were from the antibiotics and antimicrobials group: ciprofloxacin chloramphenicol, chlorotetracyclin, enrofloxacin, erythromycin, fenbendazole, florfenicol, lincomycin, oxitetracyclin, roxithromycin, sulfamethoxazole, sulfamethazine, sulfathiazole trimethoprim and tylosin. One pharmaceutical was from beta blockers group: atenolol. Lastly, one was the most commonly used stimulant: caffeine. Caffeine was selected because it is not only used as a stimulant in medicines but also in various food and beverages and consumed by people in their daily life worldwide. The structures and chemical formulae and basic information of selected pharmaceuticals are shown in Table 3.3.

3.3 Experimental Analyses

Experimental analysis was consisting of two parts:

1) Solid phase extraction (SPE) of water and wastewater samples
2) Determination of the target pharmaceuticals in extracted samples by HPLC/MS/MS.

3.3.1 Solid Phase Extraction (SPE)

Solid phase extraction (SPE) is a process used to separate compounds dissolved or suspended in a liquid. Solid state extraction is an extremely efficient method for isolating and concentrating solutes from relatively large volumes of liquid. This technique can be very effective, even when the solutes are present at extremely dilute concentrations (e.g. ppb).

Samples Preparation

Ciprofloxacin -13C3- 15N; cotinine - d3; erythromycin -13C2; ibuprofen-13C3; naproxen – 13C1- d3; simeton; sulfamethazine -13C6; 2,4,5-trichloramphenoxy acid -13C6 and trimethoprim-13C3 were used as internal

standards. All standards were dissolved in methanol and diluted to final stock solutions of 1 g/L. Stock solutions were prepared just before use, but when necessary were kept in the air-tight glass bottles and stored in a freezer.

Table 3.3 Information of target pharmaceuticals

Pharmaceutical	**CAS No.**	**Formula**	**Mol. W. (g/mol)**	**Drug Class**
Acetaminophen	103-90-2	$C_8H_9NO_2$	151.2	Acidic Drugs / NSAID
Acetylsalicylic A.	50-78-2	$C_9H_8O_4$	180.1	Acidic Drugs / NSAIDs
Atenolol	29122-68-7	$C_{14}H_{22}N_2O_3$	266.34	Beta-blocker
Caffeine	58-08-2	$C_8H_{10}N_4O_2$	194.2	Stimulant
Chloramphenicol	56-75-7	$C_{11}H_{12}C_{l2}N_2O_5$	323.1	Bacteriostatic Antimicrobial Antibiotics
Chlortetracycline	57-62-5	$C_{22}H_{23}ClN_2O_8$	478.9	Tetracycline Antibiotics
Ciprofloxacin	85721-33-1	$C_{17}H_{18}FN_3O_3$	331.3	Fluoroquinolone Antibiotics
Diclofenac	15307-86-5	$C_{14}H_{11}C_{l2}NO_2$	296.1	Acidic Drugs / NSAIDs
Enrofloxacin	93106-60-6	$C_{19}H_{22}FN_3O_3$	359.4	Fluoroquinolone Antibiotics
Erythromycin	114-07-8	$C_{37}H_{67}NO_{13}$	733.9	Macrolides Antibiotics
Fenbendazole	43210-67-9	$C_{15}H_{13}N_3O_2S$	299.349	Antiphrastic
Florfenicol	73231-34-2	$C_{12}H_{14}C_{l2}FNO_4S$	358.2	Broad Spectrum Antibiotic
Ibuprofen	15687-27-1	$C_{13}H_{18}O_2$	206.2	Acidic Drugs /NSAIDs
Lincomycin	154-21-2	$C_{18}H_{34}N_2O_6S$	406.5	Lincosamide Antibiotic
Mefenamic Acid	61-68-7	$C_{15}H_{15}NO_2$	241.3	Acidic Drugs /NSAIDs
Naproxen	22204-53-1	$C_{14}H_{14}O_3$	230.3	Acidic Drugs /NSAIDs
Oxytetracycline	79-57-2	$C_{22}H_{24}N_2O_9$	460.4	Tetracycline Antibiotics
Roxithromycin	80214-83-1	$C_{41}H_{76}N_2O_{15}$	837	Macrolides Antibiotics
Sulfamethazine	57-68-1	$C_{13}H_{15}N_3O_2S$	277.3	Sulfonamide Antibiotics
Sulfamethoxazole	723-46-6	$C_{10}H_{11}N_3O_3S$	253.3	Sulfonamide Antibiotics
Sulfathiazole	72-14-0	$C_9H_9N_3O_2S_2$	255.3	Sulfonamide Antibiotics
Trimethoprim	738-70-5	$C_{14}H_{18}N_4O_3$	290.3	Dihydrofolate Antibiotics
Tylosin	1401-69-0	$C_{46}H_{77}NO_{17}$	916.1	Macrolides Antibiotic (Veterinary)

Note: Mol. W. = Molecular Weight

Samples (500 mL) were first filtered with glass microfiber filter papers (Whatman, GF/B, 1.0 µm, Adelaide Co., Thailand), and were subsequently adjusted to pH 3 with acetic acid. The 50 µL of internal standard (IS) was spiked before solid phase extraction (SPE). SPE was performed by using 1g HLB cartridges (Waters-Millford, MA, USA). The cartridges were preconditioned with 12 mL of methanol and 12 mL of Milli-Q water. The samples were introduced to the cartridges at a flow rate of 10 mL/min. After loading sample, the cartridge was washed with 12 mL of Milli-Q water and 6 mL of hexane and allowed to dry for 1-2 min. The pharmaceuticals retained were eluted with 10 mL methanol. Subsequently, the methanol extracts were concentrated to 500 µL using centrifugal evaporator (CVE-3100, EYELA, Japan) at 40 °C and at a speed of 7000 rpm. 100 µL of concentrated sample and equal volume of de-ionized water were mixed and centrifuged to eliminate suspended particulates. The supernatant was transferred to amber vials with 250 µL polypropylene insert for HPLC/MS/MS analysis. The steps of SPE process are shown in Fig 3.12.

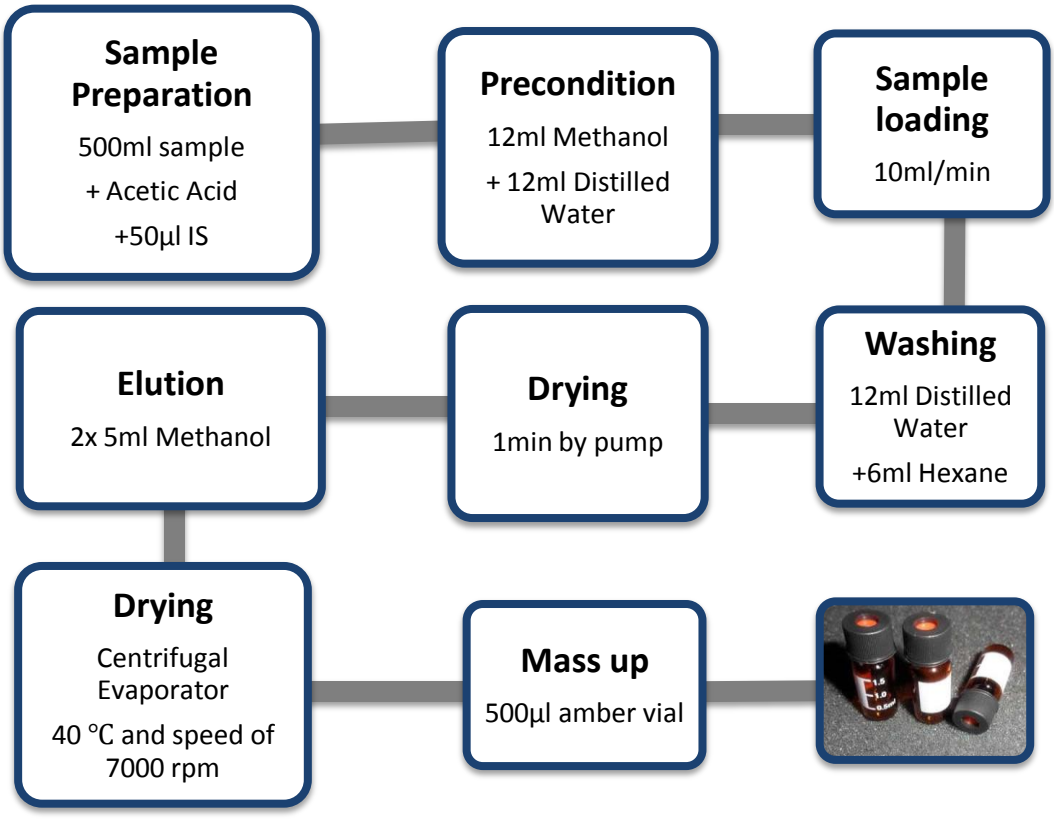

Fig. 3.12 Solid phase extraction (SPE) process

3.3.2 High Performance Liquid Chromatography Triple Quadrupole Mass Spectrometry - Mass Spectrometry (HPLC/MS/MS)

High performance liquid chromatography-mass spectrometry (HPLC-MS, or alternatively LC-MS) is an analytical chemistry technique that combines the physical separation capabilities of HPLC with the mass analysis capabilities of mass spectrometry. HPLC-MS is a powerful technique used for many applications which has very high sensitivity and selectivity. In this study, all water / wastewater samples were analyzed using a triple quadrupole mass spectrometer (API 4000, Applied Biosystems, USA) equipped with an electron spray ionization source and operated in the positive and negative ion modes. The HPLC separations were carried out by the Agilent 1100 series equipment (Agilent Technologies, USA) consisting a binary pump, a vacuum degasser, an auto sampler, and a thermostat column. Details of the analytical operating conditions for HPLC/ESI-MS/MS are summarized in Table 3.4.

The MS/MS conditions were optimized by infusion of 50 ng/μL solutions of every standard into the mass spectrometer with a syringe pump at 10 μL/ min for the negative ion mode operating. MRM-MS-MS was performed on the protonated molecular ions for target compounds by using the following general parameters: source voltage = 5.5 kV; capillary temperature = 400 °C; collision-activated dissociation = 7; entrance potential = 10.0 V and dwell time = 45 ms. The HPLC (1100 series, Agilent Technologies) program in a gradient mode is shown in the Table 3.4. Target compounds were separated in a reverse phase C18 column (3μm, 2.0 X 150 mm, YMC ODS-AQ). Mobile phase flow rate was 200 μL/ min and injection volume was 5 μL.

The MS/MS (API 4000, Applied Biosystems) conditions were optimized by infusion 50 ng/μL solutions of every standard into the mass spectrometer with a syringe pump at 10 μL/min for the negative ion mode operating. MRM MS/MS was performed on the deprotonated molecular ions for target compounds by using the following general parameters: source voltage = - 4.5 kV; capillary temperature = 400 °C; collision-activated dissociation = 5; entrance potential = -10.0 V, and dwell time = 60ms. The HPLC (1100 series, Agilent Technologies) program in a gradient mode is

showed in the table 3.3. Target compound was separated on a reverse phase C18 column (3µm, 2.0 X 150 mm). Mobile phase flow rate was 200 µL/min and injections volume was 5 µL.

Table 3.4 Analytical operating conditions for LC/ESI-MS/MS

	Parameters	**Operating Conditions**	
		Positive ion mode	**Negative ion mode**
HPLC	LC Column	ODS-AQ(YMC) C_{18}, 2.0×150mm, 3 µm	Luna (Phenominex) C_{18}, 2.0×150mm, 3 µm
	Mobile phase	A : 10mM ammonium formate and 0.3% formic acid in Water B : Methanol	A : 5mM ammonium acetate in Water B : Methanol
	Gradient(200 µl/min)	Time(min) 0 10 16 17 28 B % 10 95 95 10 10	Time(min) 0 6 10 10.1 21 B % 10 95 95 10 10
	Flow (µl /min)	200	200
	Run time (min)	28	21
	Injection volume	5 µL	5 µL
	Column temperature	20°C	20°C
MS/MS	Type Ionization mode	MRM (multiple reaction mode) ESI negative	MRM (multiple reaction mode) ESI negative
	Curtain Gas	15 psi	15 psi
	Gas temperature	400 °C	400 °C
	Ion Spray Voltage	5500 V	-4500 V
	Ion Source Gas 1	40 psi	40 psi
	Ion Source Gas 2	60 psi	60 psi
	Collision Gas (CAD)	7	5

The mass spectrometric characteristics for the target compounds detected in positive ion mode and negative ion mode are shown in Table 3.5 and Table 3.6, respectively.

The detailed list of all compounds with the limits of detection (LOD) and quantification (LOQ) are shown in Table 3.7. LOD was calculated when the signal to

noise ratio was equal to 3. The LOQ value was three times of LOD.

Table 3.5 Mass spectrometric characteristics for the target compounds (positive ion)

Target Compounds	RT (min)	Precursor ion (Q1, m/z)	Product ion(Q3, m/z)		Declustering Potentials (V)	Collision Energy (V)
			Confirm ion	Quantitation ion		
Acetaminophen	10.1	152.2	93.0	110.1	61	33/23
Caffeine	12.0	195.1	123.2	138.0	21	49/29
Chlortetracycline	12.9	479.2	462.1	444.0	76	25/29
Ciprofloxacin	12.0	332.2	245.3	288.2	76	35/27
Enrofloxacin	11.9	360.0	245.0	316.0	76	39/29
Erythromycin	14.3	734.6	576.5	158.1	76	29/45
Lincomycin	10.7	407.2	359.1	126.1	91	27/39
Oxytetracycline	11.9	461.2	443.1	426.0	51	19/27
Roxithromycin	14.9	837.7	679.2	158.0	66	33/53
Sulfamethazine	11.6	279.2	124.0	186.2	56	41/25
Sulfamethoxazole	12.3	254.2	108.0	156.2	51	37/25
Sulfathiazole	10.5	256.0	108.0	156.0	56	37/23
Trimethoprim	10.9	291.2	123.1	230.0	81	35/31
Atenolol	9.2	267.2	190.1	145.1	66	27
Fenbendazole	16.3	300.3	268.1	159.2	86	29
Tylosin	14.2	917	174.3	101.3	86	14

Note: RT = Retention Time

Table 3.6 Mass spectrometric characteristics for the target compounds (negative ion)

Target Compounds	RT (min)	Precursor ion (Q1, m/z)	Product ion (Q3, m/z)		Declustering Potentials (V)	Collision Energy (V)
			Confirm ion	Quantitation ion		
Acetylsalicylic acid	9.8	136.9	64.9	93.0	-50	-42/-22
Chloramphenicol	11.3	320.9	257.0	152.0	-65	-16/-24
Diclofenac	13.1	293.9	213.8	250.0	-55	-30/-16
Florfenicol	10.6	357.2	186.0	336.8	-50	-26/-14
Ibuprofen	13.4	205.1	159.0	161.0	-45	-10/-10
Mefenamic acid	13.6	240.0	191.9	195.9	-65	-38/-24
Naproxen	12.2	229.1	170.0	185.0	-30	-22/-10

Note: RT = Retention Time

Table 3.7 Limits of detection (LOD) and limits of quantification (LOQ)

Compounds	Linearity (r2)	Slope	STE	LOD (ng/L)	LOQ (ng/L)
Negative mode					
Acetylsalicylic acid	0.9987	0.0076	0.005901	2.6	7.7
Chlorampenicol	0.9998	0.0060	0.001958	1.1	3.2
Diclofenac	0.9957	0.0081	0.012812	5.2	15.7
Florfenicol	0.9998	0.0018	0.000656	1.2	3.6
Ibuprofen	0.9992	0.0049	0.003392	2.3	6.9
Mefenamic acid	0.9986	0.0199	0.017972	3.0	8.9
Naproxen	0.9995	0.0069	0.003173	1.5	4.6
Positive mode					
Acetaminophen	0.9997	0.0060	0.002517	1.4	4.2
Atenolol	0.9985	0.0035	0.003006	2.8	8.5
Caffeine	0.9997	0.0025	0.001026	1.4	4.1
Ciprofloxacin	0.9990	0.0087	0.005952	2.3	6.8
CTC	0.9954	0.0001	0.000161	10.6	31.9
Enrofloxacin	0.9990	0.0021	0.001448	2.3	6.8
Erythromycin	0.9999	0.0114	0.002763	0.8	2.4
Fenbendazole	0.9993	0.0307	0.017642	1.9	5.7
Lincomycin	0.9998	0.0086	0.002311	0.9	2.7
OTC	0.9876	0.0005	0.011891	78.5	235.4
Roxithromycin	0.9997	0.0057	0.002044	1.2	3.6
SMX	0.9995	0.0041	0.002262	1.8	5.5
SMZ	1.0000	0.0136	0.001891	0.5	1.4
STZ	1.0000	0.0039	0.000237	0.2	0.6
Trimethoprim	0.9994	0.0074	0.004373	2.0	5.9
Tylosin	0.9940	0.0001	0.000567	18.7	56.1

Note: STE = Standard Error LOD = Limits of quantitation**,** LOD = limits of detection FDA = Food and drugs administration, LOD = 3.3*STE/slope (FDA method), LOQ = 3* LOD

3.4 Precipitation Data

Precipitation data for the study area was collected from the Royal Thai Metrological Department, Bang Na, Bangkok, Thailand. This was use to find the effect of precipitation on the dilution of the residual of pharmaceuticals in wastewater treatment plants and receiving water bodies.

3.5 Population Data

Information about the number of people served by the WWTPs were obtained from the treatment plants. This was used to evaluate the effect of the removal processes in WWTPs on the removal of pharmaceuticals

3.6 Ecological Risk Assessment Calculation

The environmental risks of the selected pharmaceuticals were assessed by calculating toxicity of each target compound. Toxicity is often characterized by the hazard quotient (HQ) of the substance. It is obtained by comparing the measured environmental concentration (MEC) with the predicted no effect concentration (PNEC). Hazard quotients (HQs) were calculated from the measured environmental concentrations (MEC) and 95% UCL of mean, divided by the predicted no-effect concentration (PNEC) of each test pharmaceutical. To reflect more conservative exposure scenario, maximum occurrence data were used for MEC calculation.

HQ = MEC / PNEC, of the test pharmaceutical

Where,

HQ = hazard quotient

MEC = Measured environmental concentration

PNEC = Predicted no effect concentration

The PNECs were derived from the effect levels of the most sensitive test organism as reported in literature. The potential environmental risk of the target pharmaceuticals were assessed based on the ‘‘worst case scenario’’ in accordance with the European Commission Technical Guidance Document (TGD) on risk assessment (EC, 2003). An assessment factor of 1,000 was applied to the lowest value of effective concentration (EC_{50}) to account for long-term sub-chronic effects on other sensitive ecological receptors. When chronic no observed effect concentration

(NOEC) values for one, two, or three trophic levels were available, the corresponding assessment factors used were 100, 50 and 10, respectively (Table 3.8).

PNECs were derived from the effect levels of the most sensitive test organism, obtained from the literature with appropriate assessment factor.

HQ = > 1, indicates high ecological risk.
HQ = 0.5 - < 1, indicates less/moderate ecological risk.
HQ = less than 0.5, indicates negligible/low ecological risk

The pharmaceuticals, for which the calculated hazard quotient (HQ) is greater than one, certainly can be considered with potential environmental risk and need to be further investigated.

Table 3.8 Assessment factors recommended to derive predicted no observable adverse effects concentrations (NOECs)

Available Data	Assessment Factor
At least one short-term lethal concentration (e. g., LC_{50}) from each of three trophic levels of the base set (fish, Daphnia and algae)	1,000
One long-term NOEC (either fish or Daphnia)	100
Two long-term NOECs from species representing two trophic levels (fish and/or Daphnia and/or algae)	50
Long-term NOEC from at least three species (normally fish, Daphnia and algae) representing three trophic levels	10

Source: (TGD, 2003)

3.7 Experimental Plan

The experimental plan was divided into two parts as shown below.

3.7.1 Seoul, South Korea

Wastewater samples were collected from influents, mid-process and

effluents of four sewage treatment plants (STPs) in Seoul along the Han River, in March, 2011. The solid phase extractions (SPE) for the wastewater samples followed by the HPLC/MS/MS analyses were carried out at the School of Human and Environmental Science, Eulji University, South Korea.

3.7.2 Bangkok, Thailand

Water and wastewater samples were collected from influents, mid-process and effluents of five wastewater treatment plants (WWTPs) along the Chao Phraya River in Bangkok, as well as from the downstream receiving water bodies (six canals and Chao Phraya River) during the three sampling events (June 2011, September 2011 and January 2012). Solid phase extractions for the samples were carried out in Environmental Engineering Laboratory, Faculty of Engineering, Mahidol University after each sampling event. The extracted samples were shipped to School of Human and Environmental Science, Eulji University, South Korea for HPLC/MS/MS analyses.

The overall study plan is shown in Table 3.9.

Table 3.9 Study Plan

Period → / Activity↓	2010		2011												2012					
	Nov.	Dec.	Jan	Fab.	Mar.	Apr.	May	Jun.	Ju.	Au.	Se.	Oc.	No.	De.	Ja.	Fa.	Ma.	Ap.	Ma.	Ju.
Literature Review & Proposal writing	←	----------	→																	
Proposal Defense		←	----	→																
Experimental Work			←	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	→					
Sampling Data Analyses				←	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------	→				
Summer Internship					←	----------	----------	→												
Thesis Writing														←	----------	----------	----------	----------	→	
Paper writing & Presentations									←	----------	----------	----------	----------	----------	----------	----------	----------	----------	→	
Thesis Defense																				←→

CHAPTER IV
RESULT AND DISCUSSION

4.1 Concentrations of Pharmaceuticals in WWTPs in Bangkok during Three Sampling Events

Wastewater samples were collected from influents, mid-process and effluents of five selected wastewater treatment plants (WWTPs): Si Phraya (SP), Rattanakosin (RK), Chong Nonsi (CN), Din Daeng (DD), and Thung Kru (TK) in Bangkok during three sampling events: June and September 2011, and January, 2012. The samples were analyzed using HPLC/MS/MS techniques after solid phase extraction (SPE) to determine the pharmaceuticals' concentrations and removal efficiencies of the WWTPs. The results of three sampling events are presented in the following sections.

4.1.1 Influent, Mid-Process and Effluent Concentrations in June 2011

The concentrations of the tested pharmaceuticals in the influents, mid-process and effluents of the five municipal WWTPs in Bangkok during June 2011 sampling event are summarized in Table 4.1. Average concentrations are shown in Fig 4.1. The results show that pharmaceuticals were routinely present in the influent, mid-process and effluent with the exception of chlorotetracyclin, enrofloxacin, erythromycin, florfenicol, oxitetracyclin and tylosin. This reflects the very low usage of these six drugs in Bangkok.

Influent Concentrations

Roxithromycin was absent from all influent samples. As shown in Table 4.1, the influent concentrations of the 16 detected pharmaceuticals at the five WWTPs in Bangkok had a wide range (between 0.4 ng/L and 10,800 ng/L). Based upon the average concentrations of five WWTPs, acetylsalicylic acid (ranging from 515- 10,800

Table 4.1 Concentrations of pharmaceuticals in five WWTPs in Bangkok in June 2011

WWTPs	Caffeine			Acetylsalicylic Acid			Acetaminophen		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	4550	98.1	1720	2320	282	546	1970	ND	104
RK	3550	253	195	4590	292	380	572	168	140
TK	1450	28.9	28.7	515	173	354	223	135	151
DD	3460	29.4	52.6	10800	200	316	1880	186	734
CN	2730	27.6	249	4770	138	155	358	1.1	34.7
Max	4550	253	1720	10800	292	546	1970	186	734
Min	1450	27.6	28.7	515	138	155	223	1.1	34.7
WWTPs	**Ibuprofen**			**Mefenamic Acid**			**Atenolol**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	589.0	70	130	561	101	369	302	0.3	39.9
RK	527.0	134.0	81.4	561	411	461	169	41.6	27.7
TK	605.0	199	149	524	310	399	107	18.3	38.8
DD	1260	63.7	65.3	1340	200	331	253	23.1	62.5
CN	868.0	46.8	86.3	1010	234	217	241	6.3	16.5
Max	1260	199	149	1340	411	461	302	41.6	62.5
Min	527	46.8	65.3	524.0	101	217	107	0.3	16.5
WWTPs	**Naproxen**			**Diclofenac**			**Ciprofloxacin**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	258	28.9	68.6	119	49.7	103	85.9	65.7	99.2
RK	175	84.5	57.5	109	96.4	87.6	136	22.5	16.6
TK	146	21.5	18	99	89.2	84.1	244	116	73.2
DD	933	292	159	183	115	182	382	99.4	231
CN	363	4.3	13	165	52.6	55.1	235	64.6	73.9
Max	933	292	159	183	115	182	382	116	231
Min	146	4.3	13	98.5	49.7	55.1	85.9	22.5	16.6

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng, TK = Thung, Inf. = influent, Mid Pro. = mid-process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected.

Table 4.1 Concentrations of pharmaceuticals in five WWTPs in Bangkok in June 2011 (cont.)

WWTPs	Trimethoprim			Sulfamethoxazole			Sulfathiazole		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	50.1	9.3	23.8	2.7	9.14	11.5	346	ND	ND
RK	38	29.3	11	3.75	3.51	3.56	85.2	63.8	31.1
TK	51	5.1	10.2	6.1	10.7	9.2	74.6	95.6	ND
DD	221	2.6	17	11.4	45.5	88.9	144	55.1	159
CN	89.1	2.2	6.64	6.76	13	14.4	227	28.4	70.1
Max	221	29.3	23.8	11.4	45.5	88.9	346	95.6	159
Min	38	2.21	6.64	2.68	3.51	3.56	74.6	28.4	31.1
WWTPs	**Sulfamethazine**			**Roxithromycin**			**Chloramphenicol**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	18.1	ND	13.6	ND	1.1	1.9	0.8	ND	1.1
RK	10.6	ND	9.7	ND	7.6	0.7	2.5	2.3	0.9
TK	24.9	ND	ND	ND	2.3	1.8	0.6	ND	ND
DD	180	307	128	ND	12.3	5.8	1.8	ND	ND
CN	35.6	20.5	21.6	ND	6.9	4.6	2.0	ND	ND
Max	180	307	128	ND	12.3	5.8	2.5	2.3	1.1
Min	10.6	20.5	9.7	ND	1.1	0.7	0.6	2.3	0.9
WWTPs	**Lincomycin**			**Fenbendazole**			**Chlorotetracyclin**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	3.9	ND	ND	ND	ND	ND	ND	ND	ND
RK	3.7	ND	ND	0.4	ND	ND	ND	ND	ND
TK	6.9	ND	ND	0.4	ND	ND	ND	ND	ND
DD	33.3	0.5	0.8	ND	ND	ND	ND	ND	ND
CN	13.4	0.4	ND	ND	ND	ND	ND	ND	ND
Max	33.3	0.5	0.8	0.4	ND	ND	ND	ND	ND
Min	3.7	0.4	0.8	0.4	ND	ND	ND	ND	ND

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng, TK = Thung, Inf. = influent, Mid Pro. = mid-process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected.

Table 4.1 Concentrations of pharmaceuticals in fie WWTPs in Bangkok in June 2011 (cont.)

WWTPs	Enrofloxacin			Erythromycin			Florfenicol		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	ND	ND	ND	ND	ND	ND	ND	ND	ND
RK	ND	ND	ND	ND	ND	ND	ND	ND	ND
TK	ND	ND	ND	ND	ND	ND	ND	ND	ND
DD	ND	ND	ND	ND	ND	ND	ND	ND	ND
CN	ND	ND	ND	ND	ND	ND	ND	ND	ND

WWTPs	Oxytetracycline			Tylosin		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	ND	ND	ND	ND	ND	ND
RK	ND	ND	ND	ND	ND	ND
TK	ND	ND	ND	ND	ND	ND
DD	ND	ND	ND	ND	ND	ND
CN	ND	ND	ND	ND	ND	ND

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng, TK = Thung, Inf. = influent, Mid Pro. = mid-process, Eff. = effluent, Min = Minimum, Max = Maximum, ND = not detected.

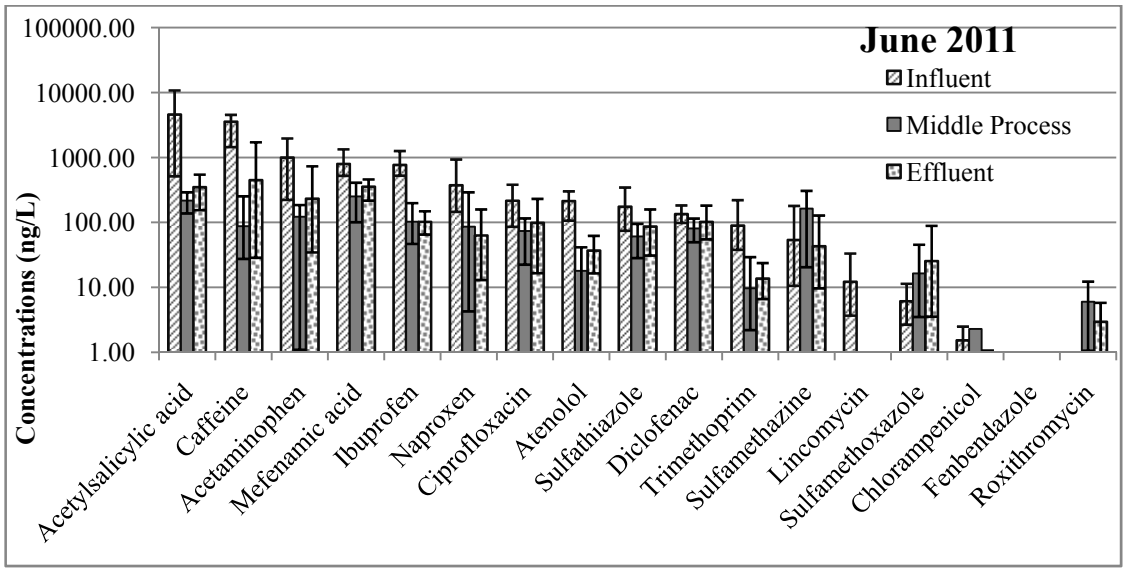

Fig. 4.1 Average levels of pharmaceuticals in five WWTPs in June 2011. (Error bars represent the maximum and minimum levels detected)

ng/L) was found to be at the highest level at 4,599 ng/L. Caffeine was detected at the second highest level on average (3,148 ng/L) in the WWTPs influents (ranging from 1,450 to 4,550 ng/L). Among all five WWTPs, caffeine was consistently found at high levels (above1,500 ng/L); this could reflect the high usage of caffeine amongst the people in Bangkok. It is also noteworthy that, caffeine is widely consumed as a stimulant and is also found in many beverages and food items such as cakes, chocolates and soft drinks. According to a report, an average Bangkok citizen consumes around 20.12 L of caffeine per year (Ministry of Finance, 2007). Trace amount of fenbendazole was detected in RK and TK plants (0.4 ng/L in both plants). On average chloramphenicol, sulfamethoxazole and lincomycin were found at very low levels (1.5 ng/L, 6.1 ng/L and 12.2 ng/L, respectively).

Mid-process Concentrations

Among all tested pharmaceuticals, fenbendazole was absent from the mid-process of all of the five WWTPs. On the other hand, although roxithromycin was absent from all influent samples but was detected in mid-process samples of all five WWTPs. The mid-process concentrations of the detected 16 pharmaceuticals: acetaminophen, acetylsalicylic acid, atenolol, caffeine, chloramphenicol, ciprofloxacin, diclofenac, mefenamic acid, ibuprofen, lincomycin, naproxen, roxithromycin, sulfamethoxazole, sulfamethazine, sulfathiazole and trimethoprim in the wastewater samples, ranged between 0.4 ng/L and 411 ng/L. The highest average level was found for mefenamic acid, ranging between 101 ng/L and 411 ng/L, with an average of 251.2 ng/L, followed by acetylsalicylic acid at the second highest level (ranging between 138 ng/L and 292 ng/L, with an average of 154 ng/L) and sulfamethazine (ranging between 20 ng/L and 307 ng/L, with an average of 163.8 ng/L). Trace amounts of lincomycin were found in only two WWTPs (0.4 ng/L in SP and 0.5 ng/L in DD). Chloramphenicol (2.3 ng/L) was only detected at the TK. Roxithromycin was found with the lowest average level (6 ng/L) ranging between 1.1 ng/L and 12.3 ng/L among all of the five WWTPs.

Effluent Concentrations

Amongst all tested pharmaceuticals, fenbendazole was absent from effluents of all the five WWTPs. The effluent concentrations of the 16 detected pharmaceuticals in the five WWTPs ranged between 0.7 ng/L and 1,720 ng/L. The highest average concentration was found for caffeine ranging between 28.7 ng/L and 1,720 ng/L, with an average of 449.1 ng/L. Interestingly, amongst all the effluent samples from the five WWTPs, the concentration of caffeine varied the most with three order of magnitude difference between the SP and the TK WWTPs. Mefenamic acid was found at the second highest average level and ranged between 217 ng/L and 461 ng/L, with an average of 355 ng/L. This was followed by acetylsalicylic acid ranging from 155 ng/L to 546 ng/L, with an average of 350 ng/L. Trace amount of lincomycin (0.8 ng/L in DD) and chloramphenicol (0.9 ng/L in SP and 1.1 ng/L in RK) were found in effluents during June 2011. Among all the five WWTPs, on an average, roxithromycin was found to be at the lowest level, ranging between 0.7 ng/L and 5.8 ng/L, with an average of 3 ng/L. This was followed by trimethoprim which ranged between 6.6 ng/L and 23.8 ng/L, with an average of 13.7 ng/L.

Many pharmaceuticals showed higher levels in effluents than in mid-process samples. This could be explained by the two reasons: 1) some of the pharmaceuticals get adsorbed in sludge but after sometimes they are released back to the wastewater. Thus, some of the accummulated mass of these pharmaceuticals could add into the effluents, and 2) many pharmaceuticals are easily transformed from their parent compounds to their metabolites and vice versa; thus the concentrations may be easily underestimated or overestimated (Jelic, et al., 2012).

4.1.2 Influent, Mid-Process and Effluent Concentrations in September 2011

The concentrations of the tested pharmaceuticals in the influents, mid-process and effluents of the five municipal WWTPs in Bangkok during September 2011 sampling event are summarized in Table 4.2. Average concentrations are shown in Fig 4.2. Among the tested pharmaceuticals, chlorotetracyclin, erythromycin,

florfenicol, oxitetracyclin and tylosin were absent from all influent, mid-process and effluent samples of the five WWTPs.

Table 4.2 Concentrations of Pharmaceuticals in five WWTPs in September 2011

WWTPs	Caffeine			Acetylsalicylic Acid			Acetaminophen		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	3090	442	1250	16000	185	247	607	7.15	10.2
RK	2150	52.4	41.4	14200	379	264	808	10.8	56.6
TK	759	27.1	14.5	655	287	493	71.9	5.04	26
DD	2890	99	14.3	2260	656	553	188	26.7	14.3
CN	1560	29.8	183	6770	226	223	67.1	3.57	17.4
Max	3090	442	1250	16000	656	553	808	26.7	56.6
Min	759	27.1	14.3	655	185	223	67.1	3.57	10.2
WWTPs	**Ibuprofen**			**Mefenamic Acid**			**Atenolol**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	631	32.9	62.9	969	199	285	304	12.4	41.5
RK	770	71.5	55.6	805	363	296	200	69.9	46
TK	385	93.5	58.4	316	226	237	91.9	6.31	24.7
DD	829	90.1	21.5	810	243	103	152	9.96	7.88
CN	535	21.7	31.2	556	118	126	111	1.11	5.34
Max	829	93.5	62.9	969	363	296	304	69.9	46.0
Min	385	21.7	21.5	316	118	103	91.9	1.11	5.34
WWTPs	**Naproxen**			**Diclofenac**			**Ciprofloxacin**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	168	14.7	30.8	260	68	92.6	244	47.2	74.3
RK	224	59.3	57.7	153	113	66.3	202	26.7	19
TK	39.1	1.16	1.21	58.3	37.5	44.3	65.5	50.2	30.4
DD	169	2.52	11.3	161	235	88.2	184	133	25.4
CN	155	0.967	8.38	98.1	22.6	24.8	146	36.8	43
Max	224	59.3	57.7	260	235	92.6	244	133	74.3
Min	39.1	1.0	1.2	58.3	22.6	24.8	65.5	26.7	19

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng and TK = Thung, Inf. = influent, Mid Pro. = mid-process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected

Table 4.2 Concentrations of Pharmaceuticals in five WWTPs in September 2011(Cont.)

WWTPs	Trimethoprim			Sulfamethoxazole			Sulfathiazole		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	47.7	8.1	15.9	5.8	6.2	8.1	138	23.8	35.8
RK	42.7	16.8	14.1	4.1	4.6	2.54	155	25.3	14.2
TK	30.0	3.8	6	6.1	3.1	10.7	42.5	16	18.6
DD	56.5	3.1	2.4	8.1	24.8	12.4	200	75.9	32.9
CN	46.9	1.3	3.0	4.9	6.4	10	112	17.1	14
Max	56.5	16.8	15.9	8.1	24.8	12.4	200.0	75.9	35.8
Min	30.0	1.3	2.4	4.1	3.1	2.54	42.5	16	14

WWTPs	Sulfamethazine			Roxithromycin			Chloramphenicol		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	18.7	12.7	10	ND	5.4	9.1	5.5	1.6	2.8
RK	10.1	3.9	2.5	ND	21.6	13.6	1.4	1.4	1.5
TK	13.1	5.5	12	ND	15.1	4.6	ND	ND	ND
DD	35.6	144	47.4	ND	42.3	6.0	2.0	0.9	ND
CN	22.1	15.1	17.1	ND	23.1	4.17	1.9	ND	ND
Max	35.6	144	47.4	ND	42.3	13.6	5.5	1.6	2.8
Min	10.1	3.9	2.5	ND	5.4	4.	1.4	0.9	1.5

WWTPs	Lincomycin			Fenbendazole			Chlorotetracyclin		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	12.5	ND	ND	0.5	ND	ND	ND	ND	ND
RK	10.9	0.6	ND	0.5	ND	ND	ND	ND	ND
TK	2.3	ND	5.1	0.6	ND	ND	ND	ND	ND
DD	9.8	0.6	ND	ND	ND	ND	ND	ND	ND
CN	4.3	ND	0.6	0.7	0.4	0.5	ND	ND	ND
Max	12.5	0.6	5.1	0.7	ND	ND	ND	ND	ND
Min	2.3	0.6	0.6	0.5	ND	ND	ND	ND	ND

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng and TK = Thung, Inf. = influent, Mid Pro. = mid-process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected

Table 4.2 Concentrations of Pharmaceuticals in five WWTPs in September 2011(Cont.)

WWTPs	Enrofloxacin			Erythromycin			Florfenicol		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	1.0	0.5	1.1	ND	ND	ND	ND	ND	ND
RK	2.1	2.5	0.5	ND	ND	ND	ND	ND	ND
TK	1.7	1.0	0.4	ND	ND	ND	ND	ND	ND
DD	ND	2.3	0.6	ND	ND	ND	ND	ND	ND
CN	0.5	1.1	1.4	ND	ND	ND	ND	ND	ND

WWTPs	Oxytetracycline			Tylosin		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	ND	ND	ND	ND	ND	ND
RK	ND	ND	ND	ND	ND	ND
TK	ND	ND	ND	ND	ND	ND
DD	ND	ND	ND	ND	ND	ND
CN	ND	ND	ND	ND	ND	ND

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng and TK = Thung, Inf. = influent, Mid Pro. = middle process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected

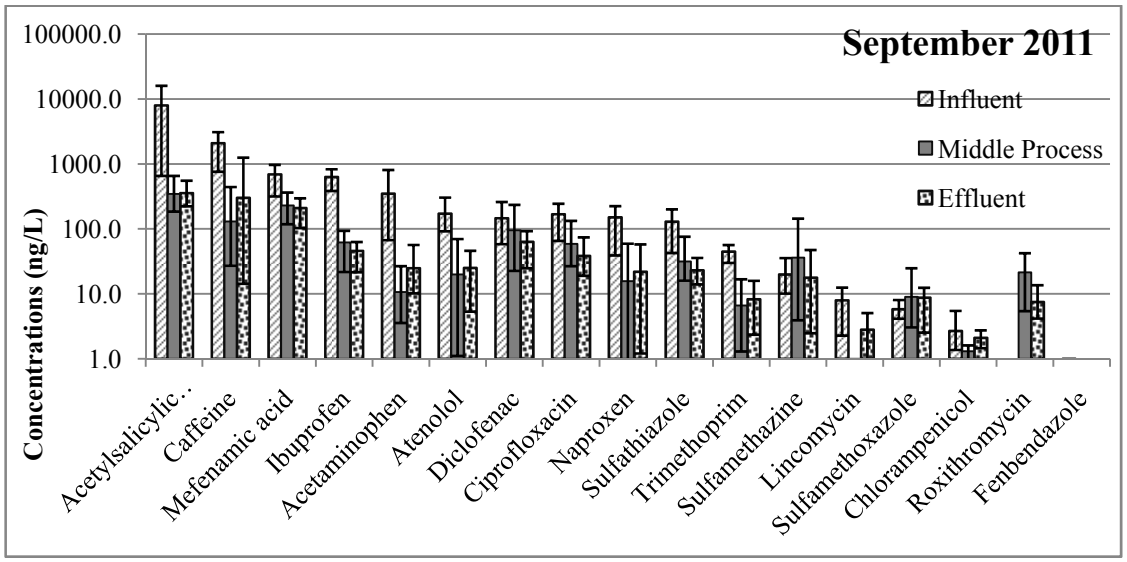

Fig. 4.2 Average levels of pharmaceuticals in five WWTPs in September 2011. (Error bars represent the maximum and minimum levels detected)

Influent Concentrations

Similar to June 2011, the top two average levels in the WWTPs influents were detected for acetylsalicylic acid and caffeine. Acetylsalicylic acid was found with the highest average concentration at 7,977 ng/L, ranging between 655 ng/l and 16,000 ng/L. Interestingly, among all the pharmaceuticals detected in the influent samples, acetylsalicylic acid displayed the widest variation with four orders of magnitude differences between the five WWTPs. Caffeine was detected at the second highest level, ranging between 759 ng/L and 3,090 ng/L, with an average of 2,089.8 ng/L. The average level of acetylsalicylic acid during September was found to be 1.73 times higher than that found in June (4,599 ng/L), whereas caffeine was found to be at lower levels in September 2011 as compared to June 2011 (3,148 ng/L). Similar to June 2011 sampling event, roxithromycin was absent from all influents. Fenbendazole was detected at the lowest average level in the influents and ranged between 0.5 ng/L and 0.73 ng/L, with an average of 0.55 ng/L. This was followed by enrofloxacin at the second lowest level ranging from 0.4 ng/L to 2.1 ng/L, with an average of 1.3 ng/L (enrofloxacin was absent from the influents of all five WWTPs during June 2011).

Mid-process Concentrations

Amongst the tested pharmaceuticals in the mid-process samples of the five WWTPs, acetylsalicylic acid was found at the highest level, ranging from 185 ng/L to 656 ng/L, with an average of 346.6 ng/L which was higher than the average concentration found in June 2011(217 ng/L). Mefenamic acid was at the second highest level with an average of 229.8 ng/L, ranging from 118 to 363 ng/L. Chloramphenicol, enrofloxacin, trimethoprim and sulfamethoxazole were found to be less than 10 ng/L and ranged from 0.9 ng/L to 24.8 ng/L. Trace amounts were detected for fenbendazole (0.4 ng/L, in CN) and lincomycin (0.6 ng/L in RK and DD). Fenbendazole and enrofloxacin were not detected in June amongst any of the mid-process samples of the WWTPs.

Effluent Concentrations

During this sampling event, pharmaceuticals' concentrations in the effluent samples were found to be less than 100 ng/L, except for acetylsalicylic acid, caffeine and mefenamic acid. The maximum average concentration was found for

acetylsalicylic acid at 356 ng/L, which was almost similar to June 2011 (350.2 ng/L). Among all detected pharmaceuticals in the five WWTPs, concentration of caffeine varied the most with three orders of magnitude differences between the minimum and maximum level. However, caffeine and mefenamic acid were found to be at lower levels (300.6 ng/L and 229.8 ng/L, respectively) than in June 2011 (449.1 ng/L and 355.4 ng/L, respectively). Trace amounts of fenbendazole (0.4 ng/L; only in TK) and enrofloxacin were found amongst all of the detected pharmaceuticals (with an average of 0.8 ng/L and ranging from 0.4 to 1.4 ng/L). However, fenbendazole and enrofloxacin were absent from all effluent samples during the June 2011 sampling event. Average concentrations of sulfamethoxazole, trimethoprim, roxithromycin, lincomycin and chloramphenicol were detected to be below10 ng/L and ranged from 0.5 to 15.9 ng/L. Whereas, in June 2011, the average concentrations of most of these pharmaceuticals were found to be above 10 ng/L, with the exception of lincomycin and roxithromycin.

4.1.3 Influent, Mid-Process and Effluent Concentrations in January 2012

The concentrations of the tested pharmaceuticals in the influents, mid-process and effluents of the five municipal WWTPs in Bangkok during January 2012 sampling event are summarized in Table 4.3. Average concentrations are shown in Fig 4.3. Similar to June 2011, chlorotetracyclin, erythromycin, fenbendazole, florfenicol, oxitetracyclin and tylosin were absent from all influent, mid-process and effluent samples of the five municipal WWTPs.

Influent Concentrations

As shown in Table 4.3, acetylsalicylic acid was detected to be at the highest level among all detected pharmaceuticals with a range between 74.5 ng/L and 3,555 ng/L and an average of 1,522.1 ng/L. This was followed by caffeine (ranging between 764 ng/L and 2,330 ng/L, with an average of 1,513.8 ng/L). During this time, the average levels of acetylsalicylic acid and caffeine in the influents were detected to be lower as compared to the last two sampling events (acetylsalicylic acid - 4,599 ng/L in June 2011 and 7,977 ng/L in September 2011 and caffeine - 3,149 ng/L in June

lowest average level in the influents and ranged between 2.3 ng/L and 4 ng/L, with an average of 2.7 ng/L. This was followed by enrofloxacin at the second lowest level

Table 4.3 Concentrations of Pharmaceuticals in five WWTPs in January 2012

WWTPs	Caffeine			Acetylsalicylic Acid			Mefenamic Acid		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	1855	198	236.5	894.5	107	132.5	514.5	167.5	183.5
RK	1235	39.9	441.5	2900	94.2	49.6	386.5	91.7	230.5
TK	2330	34.3	134.0	74.45	106.4	39.7	615.5	80.2	143.0
DD	764	13.5	13.0	186.5	59.25	71.1	310	202.5	254.5
CN	1385	16.7	33.1	3555	58.75	83.05	280.5	102.4	136.0
Max	2330	198	441.5	3555	107	132.5	615.5	202.5	254.5
Min	764	13.5	13	74.5	58.8	39.7	280.5	80.2	136
WWTPs	**Acetaminophen**			**Ibuprofen**			**Naproxen**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	485.0	49.7	26.7	472.5	124	53.9	281.5	84.5	52.2
RK	458.0	8.6	39.6	696	11.9	125.5	121	ND	30.45
TK	209.5	9.7	10.8	1175	68.3	74.25	209.5	10.47	39.6
DD	201.5	25.5	3.9	559	67.25	64.7	62.65	3.735	2.9
CN	774.5	29.0	5.8	627	75.05	88.45	125.5	57	64.15
Max	774.5	49.7	39.6	1175	124.0	125.5	281.5	84.5	64.2
Min	201.5	8.6	3.9	472.5	11.9	53.9	62.7	3.7	2.9
WWTPs	**Ciprofloxacin**			**Atenolol**			**Sulfathiazole**		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	175.5	58.1	64.4	168	9.0	26.4	103.9	13.0	49.8
RK	164	39.6	42.4	172	3.2	30.3	82.1	21.7	18.6
TK	194	50.4	71.7	142.5	10.3	26.3	70.9	78.3	90.1
DD	92.7	22.6	45.7	152	6.7	16.2	35.9	27.1	35.1
CN	103	8.3	12.4	179	41.6	59.4	82.6	48.9	57.7
Max	194	58.1	71.7	179	41.6	59.4	103.9	78.3	90.1
Min	92.7	8.3	12.4	142.5	3.2	16.2	35.9	13.0	18.6

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng and TK = Thung Kru, Inf. = influent, Mid Pro. = middle process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected.

Table 4.3 Concentrations of Pharmaceuticals in five WWTPs in January 2012 (Cont.)

WWTPs	Diclofenac			Trimethoprim			Sulfamethazine		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	67.25	28.5	63.1	31.8	11.0	9.9	27.7	8.0	22.5
RK	111	28.25	67.45	45.3	2.7	8.1	ND	11.2	ND
TK	366.5	221	177	84.7	16.5	24.7	13.0	17.0	14.0
DD	74.9	55.2	73.95	31.3	4.3	8.2	11.8	10.1	9.2
CN	97.2	111	119	28.7	17.3	18.8	30.5	20.3	22.1
Max	366.5	221.0	177.0	84.7	17.3	24.7	30.5	20.3	22.5
Min	67.3	28.3	63.1	28.7	2.7	8.1	11.8	8.0	9.2

WWTPs	Sulfamethoxazole			Roxithromycin			Enrofloxacin		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	1.3	3.0	6.4	5.9	23.7	15.1	3.4	ND	ND
RK	3.1	6.3	4.3	4.4	4.3	14.1	5.5	ND	ND
TK	6.1	13.3	12.2	9.1	39.1	28.0	2.8	ND	ND
DD	2.6	4.4	8.3	2.3	2.9	5.6	3.4	ND	2.5
CN	2.4	25.3	25.0	2.8	52.6	41.4	ND	ND	ND
Max	6.1	25.3	25.0	9.1	52.6	41.4	5.5	0.0	2.5
Min	1.3	3.0	4.3	2.3	2.9	5.6	2.8	0.0	2.5

WWTPs	Lincomycin			Chloramphenicol			Chlorotetracyclin		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	2.4	0.5	0.5	ND	ND	ND	ND	ND	ND
RK	10.9	ND	0.9	3.4	ND	ND	ND	ND	ND
TK	9.4	0.3	0.4	4.0	ND	ND	ND	ND	ND
DD	6.8	ND	ND	2.3	ND	ND	ND	ND	ND
CN	11.5	2.2	2.7	4.0	1.6	1.2	ND	ND	ND
Max	11.5	2.2	2.7	4.0	1.6	1.2	0.0	0.0	0.0
Min	2.4	0.3	0.4	2.3	1.6	1.2	0.0	0.0	0.0

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng and TK = Thung Kru, Inf. = influent, Mid Pro. = middle process, Eff. = effluent, Av = Average, Min = Minimum, Max = Maximum, ND = not detected.

Table 4.3 Concentrations of Pharmaceuticals in five WWTPs in January 2012 (Cont.)

WWTPs	Erythromycin			Fenbendazole			Florfenicol		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	ND	ND	ND	ND	ND	ND	ND	ND	ND
RK	ND	ND	ND	ND	ND	ND	ND	ND	ND
TK	ND	ND	ND	ND	ND	ND	ND	ND	ND
DD	ND	ND	ND	ND	ND	ND	ND	ND	ND
CN	ND	ND	ND	ND	ND	ND	ND	ND	ND

WWTPs	Oxytetracycline			Tylosin		
	Inf.	Mid Pro.	Eff.	Inf.	Mid Pro.	Eff.
SP	ND	ND	ND	ND	ND	ND
RK	ND	ND	ND	ND	ND	ND
TK	ND	ND	ND	ND	ND	ND
DD	ND	ND	ND	ND	ND	ND
CN	ND	ND	ND	ND	ND	ND

Note: Unit in ng/L, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng and TK = Thung Kru, Inf. = influent, Mid Pro. = middle process, Eff. = effluents, Av = Average, Min = Minimum, Max = Maximum, ND = not detected

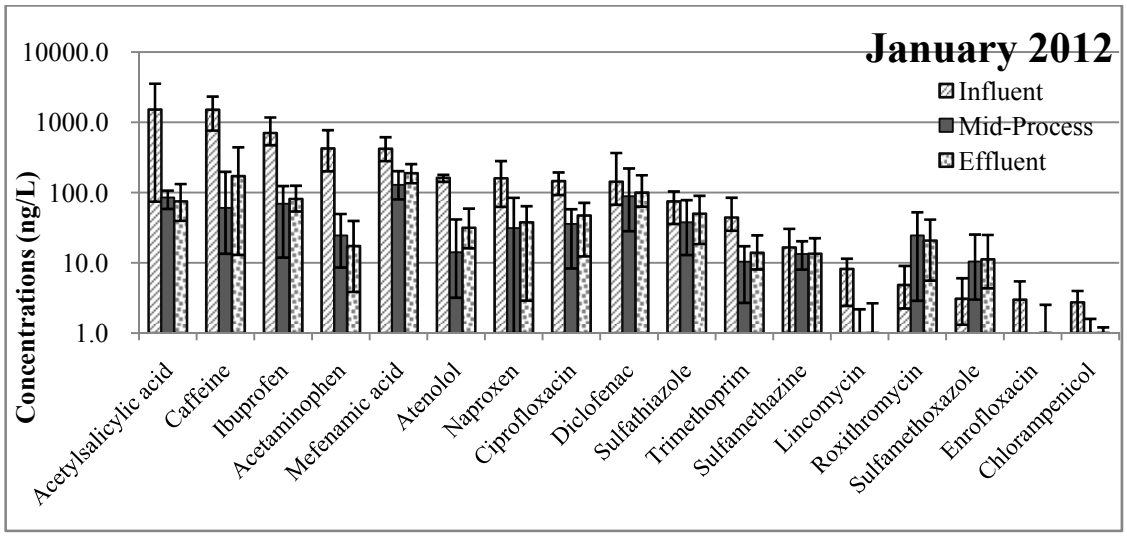

Fig. 4.3 Average levels of pharmaceuticals in five WWTPs in January 2012 (Error bars represent the maximum and minimum levels detected)

ranging between 2.8 ng/L and 5.5 ng/L, with an average of 3 ng/L. The average level of chloramphenicol in the influents was slightly higher during January 2012 (2.7 ng/L) as compared to June 2011 (1.53 ng/L). However, it was similar to the average level found in September 2011(2.7 ng/L).

Mid-process Concentrations

Similar to June 2011 sampling event, mefenamic acid was found to be at the highest level among all the tested pharmaceuticals in the mid-process samples of five WWTPs, ranging between 80.2 ng/L and 202.3 ng/L, with an average of 128.8 ng/L which were lower than in June 2011 (101 - 411 ng/L, average: 251 ng/L) and September 2011 (185 – 656 ng/L, average: 229.8 ng/L). Diclofenac was found at the second highest average level (88.8 ng/L) ranging between 28.3 and 221 ng/L. Also, enrofloxacin was absent from all of the mid-process samples of all five WWTPs like the previous two events. Trace amount of chloramphenicol (1.6 ng/L) was found in RK. However, this time the average level of chloramphenicol was found to be at slightly lower level compared to June 2011 (2.29 ng/L) and was similar to September 2011(1.3 ng/L).

Effluent Concentrations

Amongst all tested pharmaceuticals in the effluents of five WWTPs, concentrations ranged between 2.5 ng/L and 254.5 ng/L. On average, mefenamic acid (ranging between 136 ng/L and 254.5 ng/L, with an average 189.5 ng/L), caffeine (ranging between 13 ng/L and 441.5 ng/L, with an average of 171.6 ng/L) and diclofenac (ranging between 63.1 ng/L and 177 ng/L, with an average of 100.1 ng/L) were found to be at top three levels. The average levels of mefenamic acid and caffeine in the effluents were lower than the June 2011 (355.4 ng/L and 209.4 ng/L, respectively) and September 2011 (449.1 ng/L and 300.6 ng/L, respectively). This time, the average level of diclofenac (100.1 ng/L) was similar to the June (102.4 ng/L) but higher than the September 2011 (63.2 ng/L). Lincomycin was found to be at the lowest average level (1.1 ng/L) ranging between 0.4 ng/L and 2.7 ng/L. Trace amounts of chloramphenicol (1.2 ng/L in RK) and enrofloxacin (2.5 ng/L in TK) were found only in two WWTPs.

4.1.4 Comparison of Pharmaceuticals' Concentrations in WWTPs in Bangkok during the Three Sampling Events

The concentrations of the tested pharmaceuticals in the influents mid-process and effluents of the five WWTPs in Bangkok during the three sampling events are summarized in Table 4.4. Chlorotetracyclin, erythromycin, florfenicol, oxitetracyclin and tylosin were absent from all influents, mid-processes and effluent samples of the five municipal WWTPs, during the three sampling events.

Table 4.4 Average concentrations of pharmaceuticals in WWTPs during the three sampling events in Bangkok

Pharma-ceutical	Influents		Mid- Process		Effluents	
	Range	Average	Range	Average	Range	Average
AAP	67.1 - 1,974	591.6	1.1 - 186	52.6	3.9 – 734	91.7
ASA	74.5 - 16,000	4699.4	58.8 - 656	216.2	39.7 – 553	260.5
ATEN	91.9 - 304	183.0	0.3 - 69.9	17.3	5.3 - 6.5	31.3
CAF	759 - 4,550	2250.5	13.5 - 442	92.6	13 -1,720	307.1
CAP	0.6 - 5.5	2.3	0.9 - 2.3	1.3	0.9 - 2.8	1.1
CPF	65.5 - 382	176.9	8.3 - 133	56.1	12.4 – 231	61.5
DCF	58.3 - 366.5	141.5	22.6 - 235	88.2	24.8 – 182	88.6
ENRO	0.45 - 5.47	2.5	0.5 – 2.5	1.5	0.4 -2.53	1.1
FBD	0.39 – 0.7	0.5	0.4	0.4	0.05	0.5
IBP	385 - 1,260	701.9	11.9 - 199	78.0	21.5 – 149	76.6
LCM	2.3 - 33.3	9.5	0.3 - 2.2	0.5	0.5 - 5.1	1.5
MFA	280.5 - 1,340	637.3	80. - 411	203.3	103 – 461	251.4
NPX	62.7 - 933	228.7	1 - 292	44.4	1.2 – 159	41.0
RTM	2.3 - 9.1	1.6	1.1 - 52.6	17.4	0.7 -41.4	10.4
SMX	1.3 - 35.6	30.1	3 - 144	71.1	2.5 -88.9	24.9
SMZ	4.1 - 180	5.0	3.1 - 307	12.0	2.5 – 128	15.2
STZ	35.9 - 346	126.6	13 - 95.6	43.4	14 – 159	53.4
TMP	28.7 - 221	59.6	1.3 - 29.3	8.9	2.4 - 24.7	12.0

Note: Unit in ng/L, ND = not detected

Influent Concentrations

As shown in Table 4.4, the concentrations of the selected pharmaceuticals in the influents of five WWTPs during three sampling events ranged from ng/L - µg/L,

with 86.7% of the values to be less than 1μg/L. Among the tested pharmaceuticals, acetylsalicylic acid and caffeine were detected at the highest levels in the influents. The maximum concentration of acetylsalicylic acid in WWTP influent samples was 16,000 ng/L, with an average of 4,699.4 ng/L. Interestingly, the levels of acetylsalicylic acid varied with four orders of magnitude differences during June as well as September, 2011 sampling events. The average level of acetylsalicylic acid during September, 2011 (7,977 ng/L) was the highest (5.2 times higher than the January 2012 (1,522.1 ng/L)). The second highest levels were found for caffeine, ranging between 759 ng/L and 4,550 ng/L, with an average of 2,250.53 ng/L. In a previous study conducted in Bangkok, Thailand during 2009 and 2010, the average caffeine level was 9,052ng/L (Li et al., 2012). The average levels of caffeine (2,250.53 ng/L) in Bangkok in present study, however appeared to be lower than those in other countries such as Korea, Spain, USA, and Taiwan (2,600 – 48,658 ng/L) (Carballa, et al., 2004; Choi et al., 2008; Lin et al., 2010; Sim et al., 2010; Spongberg and Witter, 2008). The third highest concentration was detected from ibuprofen (IBP) ranging between 385 ng/L and 1,340 ng/L, with an average of 702 ng/L. The average influent concentration of ibuprofen in five WWTPs was almost consistent throughout the sampling events. Ibuprofen is listed as one of the top 50 dispensed pharmaceuticals in Bangkok (Ministry of Finance, 2007), and this may explain high levels of detection in the water to certain extent.

The concentrations of antibiotics were detected at between 1.3 and 382 ng/L, which were lower than those of non-steroidal anti-inflammatory drugs (NSAIDs) (39.1 – 16,000 ng/L). Among the antibiotics and antimicrobials, ciprofloxacin and sulfathiazole were detected in the highest concentrations with average concentrations of 177 ng/L and 126.6 ng/L, respectively. Roxithromycin was absent in all influents during the June and September 2011 sampling but was detected at low levels in January 2012, ranging between 2.3 – 9.1 ng/L, with an average of 4.86 ng/L. This observation is in contrast to Li et al. (2012) reporting roxithromycin at relatively high concentrations of an average of 235 ng/L in the WWTP influents. Sulfamethoxazole was also detected at lower levels with an average of 10.2 ng/L. This antibiotic was frequently detected in the influents of WWTPs in many other

countries. The average level ranged between 20 and 580 ng/L in USA and some European countries, and between 156 and 1760 ng/L in some Asian countries like Korea and Taiwan (Bendz et al., 2005; Carballa et al., 2004; Choi et al., 2008; Gros et al., 2009; Lin et al., 2010).

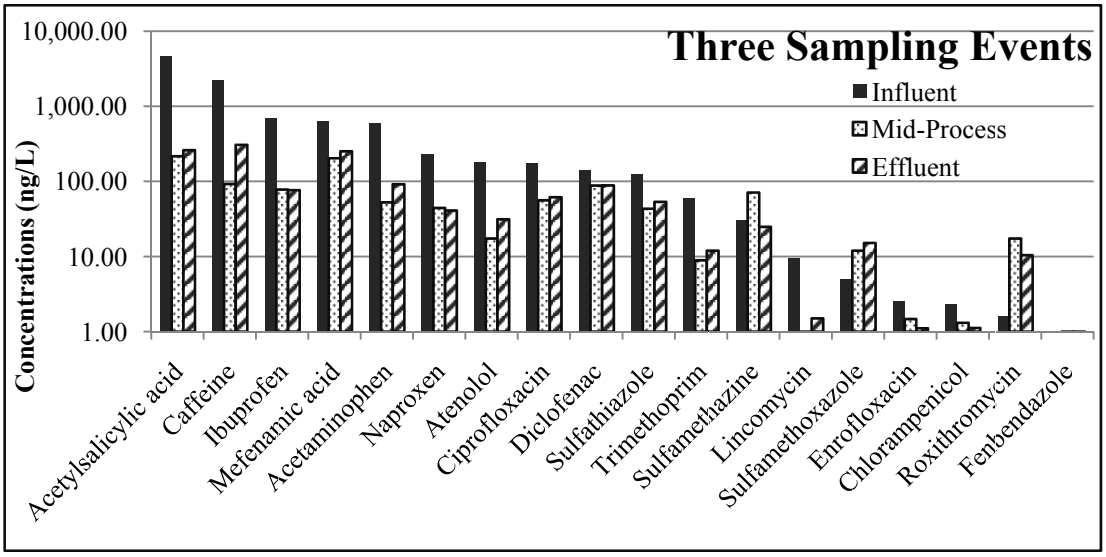

Fig. 4.4 Average levels of pharmaceuticals in WWTPs in Bangkok during the three sampling events

Mid-process Concentrations

Concentrations of the tested pharmaceuticals in the mid-process samples ranged between 0.7 and 656 ng/L during the three sampling events. On an average, acetylsalicylic acid was detected at the highest level ranging between 58.8 ng/L and 656 ng/L with an average of 216.2 ng/L in the three sampling events. This was followed by mefenamic acid (ranging between 80.2 ng/L and 411 ng/L with an average of 203.3 ng/L), caffeine (ranging between 13.5 ng/L and 442 ng/L with an average of 92.6 ng/L) and diclofenac (ranging between 22.6 ng/L and 235 ng/L with an average of 88.2 ng/L). Trace amounts of fenbendazole (0.4 ng/L) were detected in the CN only during the September 2011 sampling event. On an average, lincomycin was found to be at lowest level, ranging between 0.3 ng/L and 2.2 ng/L with an average of 0.7 ng/L. This was followed by chloramphenicol ranging between 0.9 ng/L and 2.3 ng/L with an average of 1.4 ng/L. Enrofloxacin was detected only during

September 2011 sampling event (ranging between 0.5 ng/L and 2.5 ng/L with an average of 1.5 ng/L).

Effluent Concentrations

The concentrations of the pharmaceuticals amongst all effluent samples ranged between 0.7 and 1720 ng/L during the three sampling events. All the concentrations were detected to be less than 1μg/L except for caffeine which was found at higher levels in the effluents from SP in June 2011(1,720 ng/L) and September 2011 (1,250 ng/L). The highest concentration level was found for caffeine which ranged between 13 ng/L and 1,720 ng/L with an average of 307.1 ng/L in all of the five WWTPs during the three sampling events**.** However, the average caffeine concentration observed in this study appeared to be much lower than those reported previously in Bangkok (797 ng/L) (Li et al., 2012). The reported levels of CAF in some countries also varied substantially (Canada - 50 ng/L; Australia - 1,740 ng/L) (Chan et al., 2006; Ying et al., 2009). The second highest concentration levels were found for acetylsalicylic acid which ranged between 155 ng/L and 553 ng/L with an average of 353.1ng/L. This was followed by mefenamic acid (MFA) whose concentration levels ranged between 103 ng/L and 461 ng/L with an average of 282.4ng/L. Trimethoprim was the pharmaceutical that displayed the lowest average level in the effluents with an average of 11.97 ng/L (concentrations ranging between 2.36 and 24.65 ng/L). It was followed by sulfamethazine, at the second lowest level whose concentration levels ranged from 2.54 ng/L to 128 ng/L with an average of 21.2 ng/L. It is noteworthy that the concentrations of four pharmaceuticals - roxithromycin, sulfamethoxazole, sulfamethazine and sulfathiazole in the effluents were found to be higher than those detected in the influents in many cases. Similar results were observed for several antibiotics e.g. sulfonamides, macrolides and trimethoprim in previous studies (Gobel et al., 2007, Lin et al., 2010, Ying et al., 2009). The fact that we observed greater effluent concentrations than those of influents can partly be explained by low treatment efficiency of the WWTPs and the hydraulic retention time. For certain pharmaceuticals, loads to WWTP can vary over a short period of time, and therefore sampling influent and effluent at the same time may result in the collection of sample with different sources. In addition, the negative removal can be explained

by the formation of unmeasured products of human metabolism and/or transformation products (e.g., glucuronide conjugate, methylates, and glycinates) which convert back to the parent compounds while passing through the plant. (Gobel et al., 2007; Jelic´, et al., 2012).

4.2 Removal of Pharmaceuticals in the WWTPs and the Affecting Factors

4.2.1 Removal of Pharmaceuticals in WWTPs

Removal efficiencies of the five WWTPs for all pharmaceuticals during the three sampling events, ranged from nil to 99.97% (Table 4.5). The average removal efficiencies of the five WWTPs for caffeine during three sampling events ranged between 69.7% and 98.1%, with an overall average of 88.6 %. This is somewhat lower than the removal efficiencies for caffeine reported elsewhere, ranging between 96 and more than 99 % (Kim et al., 2007; Lin et al., 2010; Ying et al., 2009). The second highest overall removal efficiency was found for ibuprofen (average of the five WWTPs was ranging between 82.9 % and 95.3%, with an overall average of 88 %), followed by acetaminophen (ranging between 64.7 and 95.8 %, with an overall average of 83.6%).

Sulfamethazine had the lowest overall removal among five WWTPs, with the average removal rates ranging between negative and 43.1 % (overall average of 26%). The second lowest removal rate was observed for diclofenac (ranging between 13.3 and 60.2 %, with an overall average of 30.7%). Similar removal rates were reported for diclofenac elsewhere (Bendz et al., 2005; Kim et al., 2007; Lin et al., 2010). No removal was found for roxithromycin and sulfamethoxazole, regardless of the treatment processes employed in the WWTPs considered in this study. Similar results for both pharmaceuticals were also observed elsewhere (Bendz et al., 2005; Clara et al., 2005; Gobel et al., 2007; Joss et al., 2005; Sim et al., 2010). The explanation for this could be the nature of disposal of pharmaceuticals. The

Table 4.5 Average removal efficiencies of WWTPs for pharmaceuticals

Pharma-ceutical	Influent (ng/L) (n=15)	Effluents (ng/L) (n=15)	Average Removal Efficiencies (%)				
	Min- Max	Min- Max	SP	RK	TK	CN	DD
AAP	67 -1970	4-734	95.9	89.3	64.7	85.3	82.7
ASA	75-16000	40-553	86.7	95.8	39.3	97.3	73.1
ATEN	92-304	5-62.5	85.8	75.8	75.4	90.3	83.9
CAF	759-4550	13-1720	69.7	96.7	98.1	81.1	97.4
CAP	0.57 - 5.47	0.9 - 2.8	11.83	41.97	41.29	76.21	76.52
CPF	66-382	12-231	39.8	88.8	58.1	71.1	62.9
DCF	58 -367	25-182	28	19.3	13.3	60.2	32.5
ENRO	0.45 - 5.45	0.4 - 2.5	26.18	75.50	50.28	5.37	51.41
FBD	0.39 - 0.73	0.5 - 0.5	-52.01	-53.38	-49.38	31.46	ND
IBP	385-1260	22-149	85.5	87.7	82.9	88.7	95.3
LCM	2.28 - 33.3	0.4 - 5.1	88.80	86.89	41.60	90.59	96.22
MFN	281-1340	103-461	56.4	44.2	22.3	65.4	79.8
NPX	39 -933	1.3-159	78.8	63.4	93.3	88.6	85.8
RTM	2.3-9	0.7 - 41	-74.2	-69.3	-71.3	-80.6	-82.5
SMX	3-30.5	2.5-89	-61.6	-15.5	-48.4	-44.4	-57.5
SMZ	1-180	3-128	30.2	37.2	43.1	20.7	-0.9
STZ	36-346	14-159	75.4	61.5	52.8	78	17.6
TMP	29-221	2.4 -25	62.7	57.5	77.9	89.5	86.3

Note: n = numbers of samples, ND = Not Detected

substances arrive into the WWTPs in unpredictable amounts and time intervals, which could be easily systematically underestimated. Whereas, effluents come from stabilization processes, and therefore the sampling in general may result in more values than influents. Furthermore, the negative removal can be explained by the formation of unmeasured products of human metabolism and/or transformation products (e.g., glucuronide conjugate, methylates, and glycinates) that passing through the plant convert back to the parent compounds (Julic, et al., 2012; Sipma, et al., 2010). Similar kind of phenomena was also observed in some other study, where higher concentrations of several antibiotics (some sulphonamides, macrolides and trimethoprim) were found in effluent samples (Gobel et al., 2007).

4.2.2 Effect of Treatment Processes on Removal of Pharmaceuticals in the WWTPs

Generally, removal of any compound during wastewater treatment is not only influenced by its physico-chemical and biological properties, but also by some other factors, such as characteristics of wastewater, and the operating conditions and treatment technology used during biological treatment in the WWTPs (Suarez et al., 2008, Gros et al., 2010). These factors usually include: temperature of operation, different kinetic behaviors of compounds (degradation rates), redox conditions and sludge retention time (SRT) and hydraulic retention time (HRT). It is not fully clear which factors could explain these variation, because in most of the cases, enough operational data were not reported.

Temperature influences the removal of PPCPs in a positive way. Many studies have reported the higher removal efficiencies observed in summer periods as compared to colder seasons (Ternes et al. 1999b). In this study, atenolol was observed to have good removal rate among all five WWTPs (ranging from 63.7 – 95.2%). In Sweden and Spain, where the climatic temperature is very low compared to Bangkok, no removal to low removal rates of atenolol were reported (Paxeus, N., 2004; Bendz, et al., 2005 and Barceló, et al.,2009). This indicates positive effect of temperature on removal of this compound.

Regarding redox conditions, as reported in some past studies, different removal efficiencies have been observed for anaerobic, anoxic and aerobic conditions (Joss et al. 2005, Gros et al., 2010). DD and CN plants employ anoxic as well as aerobic biological treatment processes for nutrient removal from wastewater. Denitrification process in the aerobic tank (anoxic treatment) appears to have positive effect on removal of pollutants. Average removal efficiencies of DD and CN plants ranged between 70.3 % and 83.1 %, with overall averages of 74.4 % and 77.5 %, respectively, during 3 sampling events. Whereas, in other three plants: SP (overall average: 68.4 %), RK (67.9%) and TK (60.18%), average removal efficiencies ranged between 58.8% and 79.1%, during 3 sampling events.

SRT is the most critical parameter for activated sludge design (aeration tank volume and requirements of oxygen) and it affects the sludge production and performance of the treatment process. It has been observed, that longer SRT influences and improves the elimination of most of the pharmaceuticals during sewage treatment (Clara et al. 2005). However, all five WWTPs have almost similar SRTs (22-25 d), and so no significant effect of it could be observed during this study.

HRT has shown the effect on elimination of some compounds. Lower removal of ibuprofen and ketoprofen were observed at shorter HRTs (TauxeWuersch et al. 2005, Gros et al, 2010). Among the five WWTPs, TK, SP and RK have the shorter HRT (6, 6.5 h and 8 h, respectively). Whereas, DD and CN have comparatively longer HRT (10 and 11 Hr, respectively). To demonstrate the pharmaceutical removal, we tried to link the removal rates of current treatment processes with compounds' degradation i.e. pharmaceuticals' half-lives ($t_{1/2}$) and HRT of each WWTP. Calculation of t½ would provide more complete information about compounds' persistence. It would be a useful indicator of compounds' degradation rate, and would also give an idea about minimum required time to achieve good removal of the compounds in the biological reactors. Since the concentrations of pharmaceuticals in various treatments process units are usually much lower than those in the biological sludge, it may be assumed that compounds' concentrations decrease over time following pseudo- first order kinetics. The half-lives of the compounds were calculated from their relation with rate loss constants (k) using following equation of first-order reaction.

$$\mathbf{t_{1/2} = \ln (2) / k}$$

Rate loss constants (k) were calculated for each compound in each WWTP as follows:

$$\mathbf{\ln (C_{eff} / C_{in}) = - k T}$$

Where,

- $\mathbf{C_{eff}}$ is the effluent concentration of a particular compound
- $\mathbf{C_{in}}$ is the influent concentrations of the compound
- **T** corresponds to the hydraulic retention time (HRT) of each plant,

In order to simplify the calculation and to obtain qualitative $t_{1/2}$, average influent and effluent levels were used, as well as negative removals were not considered in this study. To understand the effect of HRT, we considered only 2 plants: TK (short HRT - 6 h) and CN (longer HRT - 11 h). Half-lives and removal efficiencies for some of the compounds detected in these plants, are presented in Figure 4.5.

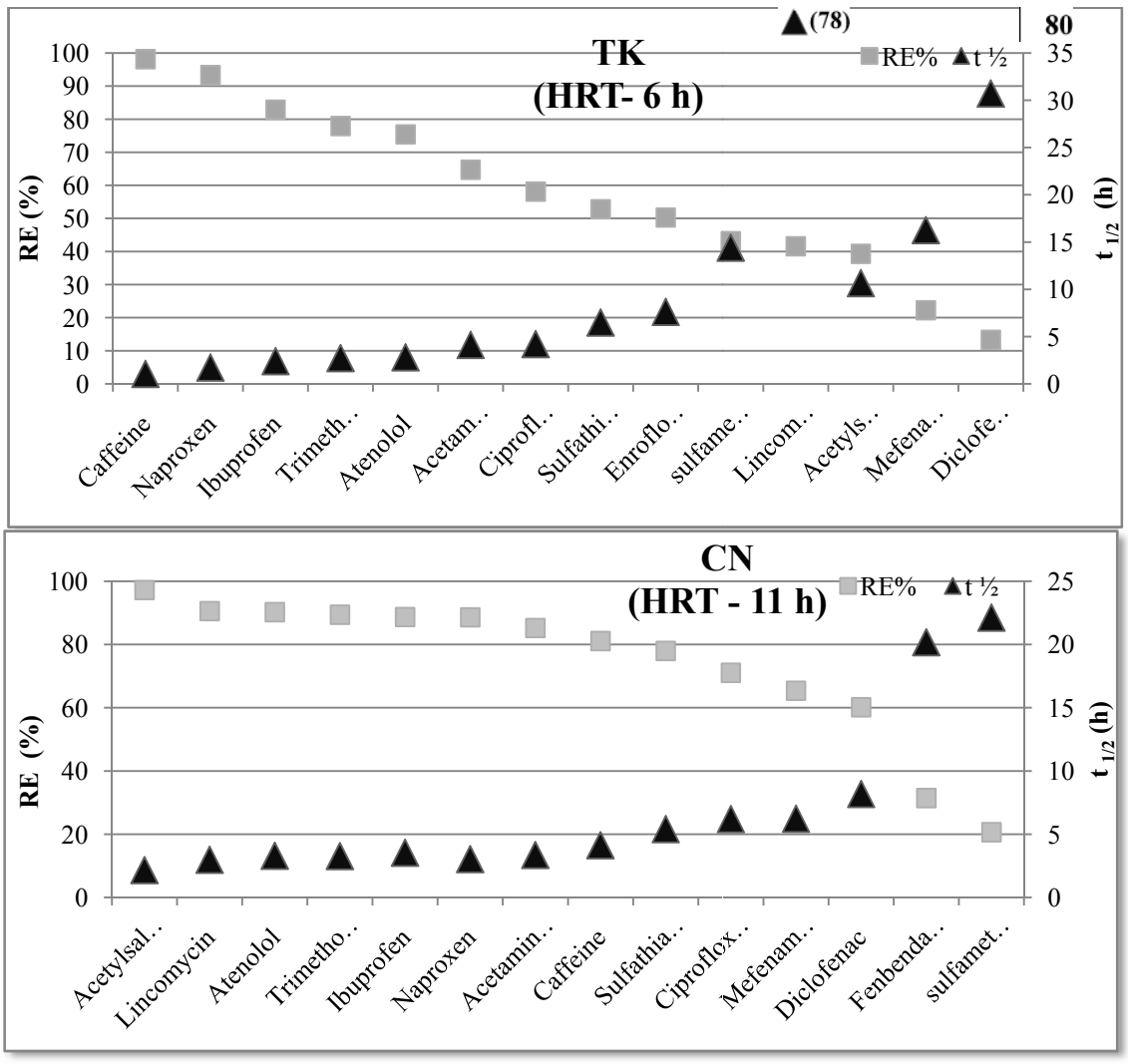

Fig. 4.5 - Half-lives ($t_{1/2}$) and removal efficiencies (RE) of the detected compounds in two WWTPs: TK (short HRT - 6 h) and CN (longer HRT - 11 h)

Based on the results of this study, it can be stated that, longer HRT is needed to accomplish the high removal of pharmaceuticals from WW. In TK, operating at lower HRT, only few compounds could decrease up to half of their initial

concentration, resulting in lower removal efficiencies. Only 3 out of 14 detected compounds in TK, could achieve more than 80 % removal, and 3 compounds had 60 - 80 % removal. Low value of $t_{1/2}$ (half life) for some non-steroidal anti-inflammatory drugs (NSAIDs) as well as of caffeine, showed the fast degradation. However, higher $t_{1/2}$ for most of the antibiotics, diclofenac and mefenamic acid showed low to a medium removal at low HRT. Whereas, longer HRT in CN, showed good removal efficiencies for most of the compounds. Eight out of 12 detected compounds had more than 80 % removal, while 4 compounds had 60 -80 % of removal. Interestingly, diclofenac and mefenamic acid had more than 60 % removal in CN, whereas in TK, they could have only 13 - 22 % removal. Most of the NSAIDs, atonal and caffeine had more than 80 % removal (Table 4.6).

Similar phenomena were observed in three other plants (SP, RK and DD) (Fig.4.6), where, removal of pharmaceuticals in WWTPs increased with HRT, as shown in Table 4.6.

Table 4.6 Effect of HRT on removal of pharmaceuticals in five WWTPs

WWTP	HRT (h)	No of detected Pharmaceuticals	No of Pharmaceuticals	
			Removal 60 – 80 %	Removal > 80 %
TK	6	14	3	3
SP	6.5	14	4	5
RK	8	13	4	6
DD	10	14	3	7
CN	11	14	4	8

Note: HRT = hydraulic retention time, SP = Si Phraya, RK = Rattanakosin, CN = Chong Nonsi, DD = Din Daeng, TK = Thung,

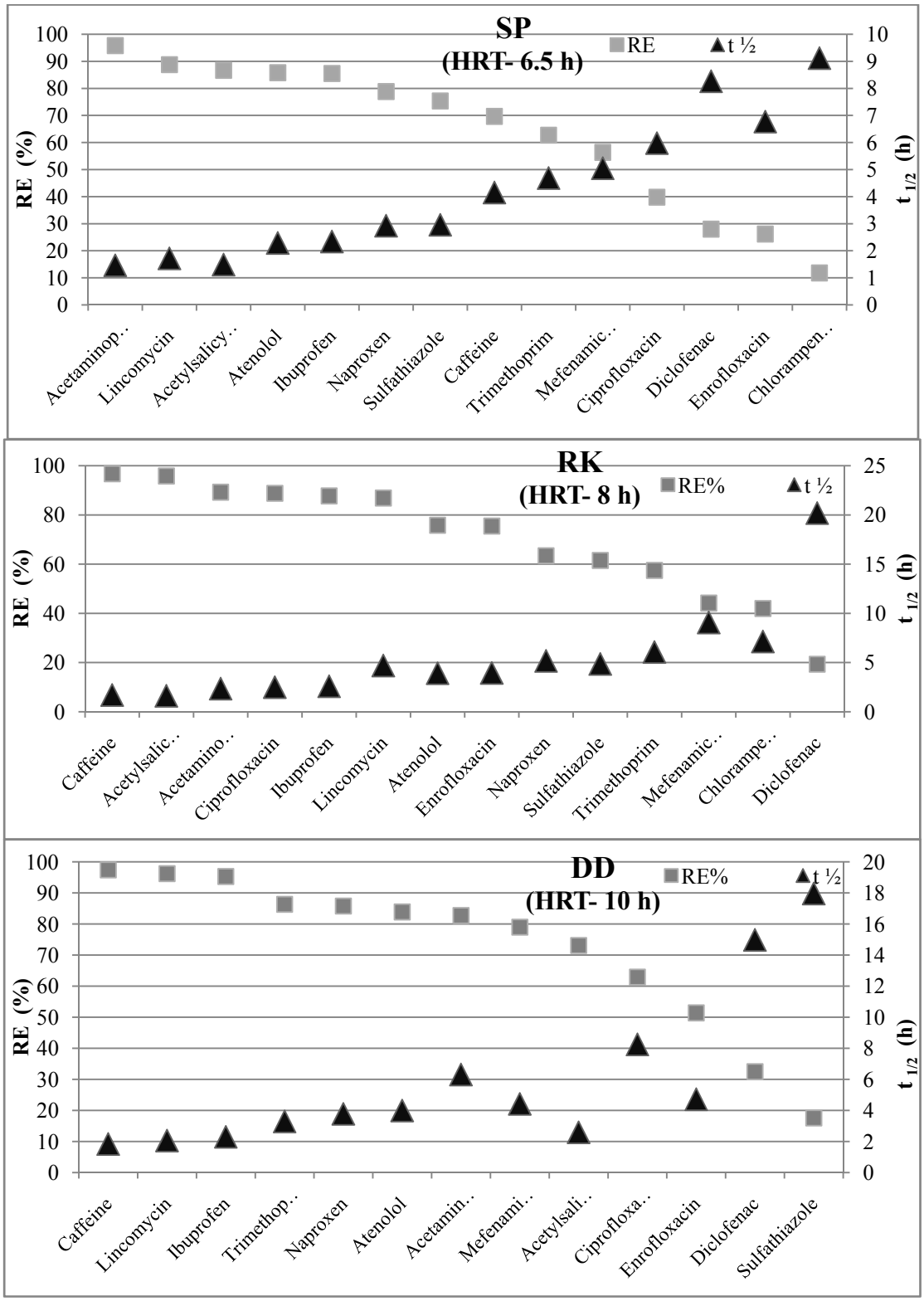

Fig. 4.6 Half-lives ($t_{1/2}$) and removal efficiencies (RE) of the detected compounds in other 3WWTPs, operating with different HRTs

Removal pattern of the detected pharmaceuticals in the five WWTPs can be summarized as follows:

(i) Five pharmaceuticals (caffeine and most NSAIDs, except diclofenac and mefenamic acid) showed high removal and fast degradation rate (low $t_{1/2}$) at low HRT.

(ii) HRT appeared to play a role on removal for 8-9 pharmaceuticals, which had higher elimination rates with increasing HRT.

(iii) HRT did not play any role on removal of two pharmaceuticals (roxithromycin and sulfamethoxazole), which showed poor or no removal and low degradation (very high $t_{1/2}$) in all the five WWTPs.

Therefore, it could be said that pharmaceuticals that are easily biodegradable (high $t_{1/2}$), and have low sludge–water distribution coefficient (k_d) - indicating low absorption in sewage sludge, are more influenced by HRT. Whereas, pharmaceuticals that have low $t_{1/2}$ and high k_d, are more influenced by SRT. However, elimination of caffeine, ibuprofen and naproxen appeared to be independent of SRT and HRT, and showed overall good removal in all five WWTPs (69.7 - 98.1%).

Based on the results of this study, it can be concluded that HRT is a key parameter regarding pharmaceuticals' removal in WWTPs. Medium to high removal could be achieved for most of the pharmaceuticals around 10 h HRT.

4.3 Concentrations of Pharmaceuticals' Residues in Six Downstream Receiving Canals in Bangkok

The six canals addressed in our study include Klong Bang Lampho (KBL), Klong Phadung Krunkasem (KPK), Klong Sam Sen (KSS), Klong Bang Jak (KBJ), Klong Kao Hong (KKH) and Klong Chon Nonsi (KCN). The canals of KBL, KPK, KSS and KBJ receive the effluents from the WWTPs of RK, SP, DD and TK, respectively. The samples were taken from upstream (before discharge, i.e., BD) and

downstream (after discharge, i.e., AD) of each of the WWTP outfall. The remaining canals of KKH and KCN do not receive the effluents from any WWTPs, and were sampled from the point before the intersection with another canal or river. The concentrations of the pharmaceuticals' residues in these canals are presented in the following sections.

4.3.1 Concentrations of Pharmaceuticals' Residues in Six Canals in June 2011

Concentrations of the tested pharmaceuticals' residues in the four receiving canals (before and after discharge point) and two non-receiving canals in Bangkok during June 2011 sampling event, are summarized in Table 4.7.

It can be seen in Table 4.7 that acetylsalicylic acid, caffeine and acetaminophen were generally detected at high levels in most of the canal samples. Acetylsalicylic acid was found to be at the highest level, ranging between 93.1 ng/L and 8,350 ng/L, with an average of 1,146.8 ng/L. This was followed by caffeine (ranging between 21.4 ng/L and 2740 ng/L with an average of 750 ng/L) and acetaminophen (ranging between 31.3 ng/L and 1,150 ng/L with an average of 401.9 ng/L). It is also noteworthy that majority of the pharmaceuticals' residues were found to be at higher levels in the four receiving canals as compared to the effluent concentrations. Moreover, the concentrations of almost 69% of the detected pharmaceuticals' residues in the two non-receiving canals (KKH and KCN) were also higher as compared to average effluent concentrations of the five WWTPs. These observations suggest that the WWTPs' effluents were not the major contributors of these chemical compounds in the canals.

Chlortetracycline erythromycin, enrofloxacin, florfenicol, oxytetracycline, and tylosin were absent from all canal samples during June 2011 (these six pharmaceuticals were also absent from all of the influents and effluents of the five WWTPs). This observation suggests that these six drugs have very low usage in Bangkok. Among the six canals samples, fenbendazole was found to be at the lowest level (ranging between 0.3 ng/L and 1.6 ng/L, with an average of 0.7 ng/L).

Chloramphenicol was found at the second lowest level (ranging between 0.6 ng/L and 1.1 ng/L, with an average of 0.9 ng/L) followed by lincomycin (ranging between 0.4 ng/L and 9.9 ng/L with an average of 2.2 ng/L) and roxithromycin (ranging between 0.4 ng/L and 9.9 ng/L, with an average of 3.8 ng/L).

Table 4.7 Concentrations of pharmaceuticals' residues in six canals in Bangkok during June 2011

Klongs	ASA	CAF	AAP	MFN	IBP	DCF	NPX	CPF
KBL-BD	239	273	83.5	416	81.2	83	45.5	0
KBL-AD	185	379	1150	556	101	104	66.4	0
KPK-BD	198	1140	307	326	314	69.5	98.7	196
KPK-AD	164	1520	31.3	301	189	68.7	63.8	144
KSS-BD	102	68.7	381	383	55.8	111	103	63.7
KSS-AD	93.1	21.4	96.1	376	50.6	122	82.2	65.7
KBJ-AD	216	196	279	227	138	52.9	11	36
KKH	774	322	634	290	296	37.3	33.6	44.3
KCN	8350	2740	655	688	622	59.6	108	11.9
Min	93.1	21.4	31.3	227.0	50.6	37.3	11.0	0.0
Max	8350.0	2740.0	1150.0	688.0	622.0	122.0	108.0	196.0
Klongs	**STZ**	**ATEN**	**SMZ**	**TMP**	**SMX**	**RTM**	**LCM**	**FBD**
KBL-BD	68.5	21.5	11.9	10.2	3.55	9.86	0.423	0.41
KBL-AD	59.6	46.4	17.5	17.2	8.37	4.4	1.6	0.75
KPK-BD	0	49.7	20.4	24.9	2.65	ND	0.904	ND
KPK-AD	64.3	31.4	13.2	23.7	6.65	ND	ND	ND
KSS-BD	71.1	20.8	85.7	5.38	41.6	3.16	0	0.30
KSS-AD	55.2	10.9	75	5.44	58.5	4.72	0	0.28
KBJ-AD	0	33.3	0	4.77	2.01	0.40	0.71	0
KKH	54.3	28.1	11.1	11.3	1.57	0.52	2	0
KCN	89.1	112	0	64.6	4.54	0	8.75	1.58
Min	0.0	10.9	0.0	4.8	1.6	0.0	0.0	0.0
Max	89.1	112.0	85.7	64.6	58.5	9.9	8.8	1.6

Note: Unit in ng/L, ND = not detected, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi, Av = Average, Min = Minimum, Max = Maximum

Table 4.7 Concentrations of pharmaceuticals' residues in canals in Bangkok during June 2011(Cont.)

Klongs	CAP	ENRO	CTC	ETM	FFN	OTC	TYL
KBL-BD	0.96	ND	ND	ND	ND	ND	ND
KBL-AD	1.14	ND	ND	ND	ND	ND	ND
KPK-BD	0.64	ND	ND	ND	ND	ND	ND
KPK-AD	ND	ND	ND	ND	ND	ND	ND
KSS-BD	ND	ND	ND	ND	ND	ND	ND
KSS-AD	ND	ND	ND	ND	ND	ND	ND
KBJ-AD	ND	ND	ND	ND	ND	ND	ND
KKH	ND	ND	ND	ND	ND	ND	ND
KCN	ND	ND	ND	ND	ND	ND	ND
Min	0.0	ND	ND	ND	ND	ND	ND
Max	1.1	ND	ND	ND	ND	ND	ND

Note: Unit in ng/L, ND = not detected, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi, Av = Average, Min = Minimum, Max = Maximum

Interestingly, all the 17 detected pharmaceuticals' residues in the canal samples, 46.6% were found at higher levels before the discharge points as compared to the effluent concentrations. This again suggests that other sources could be responsible for the presence of these compounds in the receiving canals.

4.3.2 Concentrations of Pharmaceuticals' Residues in Six Canals in September 2011

Concentrations of the tested pharmaceuticals' residues in the four receiving canals (before and after discharge point) and two non-receiving canals in Bangkok in September 2011 are summarized in Table 4.8.

It can be seen in Table 4.8, that similar to June 2011 sampling event, acetylsalicylic acid (ranging between 353 ng/L and 22,300 ng/L with an average of 2,842 ng/L), caffeine (ranging between 34.8 ng/L and 2,860 ng/L with an average of 2,825.2 ng/L) and mefenamic acid (ranging between 166 ng/L and 843 ng/L with an average of 677 ng/L) were at the top three highest levels. Moreover, the average

concentrations of these three pharmaceuticals' residues detected during this sampling event were much higher as compared to June 2011 (acetylsalicylic acid: 1,146 ng/L, caffeine: 740 ng/L and mefenamic acid: 395.9 ng/L). Interestingly, among all detected pharmaceuticals' residues, the concentrations of acetylsalicylic acid showed the widest variation in the six canals, with four orders of magnitude difference between the minimum (in canal KPK-BD) and maximum levels (canal KBL-BD). Similar to June 2011, majority of the pharmaceuticals' residues were found to be at higher levels in

Table 4.8 Concentrations of pharmaceuticals' residues in six canals in Bangkok during September 2011

Klongs	ASA	CAF	MFN	IBP	AAP	NPX	DCF	ATEN
KBL-BD	22300	2860	843	1030	711	481	209	278
KBL-AD	686	1200	428	245	144	95.5	81.4	91.1
KPK-BD	353	2770	480	420	24.3	85	78.4	105
KPK-AD	422	1970	341	243	14.5	64.3	75.5	67.7
KSS-BD	686	1010	393	393	141	43.3	71.4	69.6
KSS-AD	424	133	178	55.9	29.5	22.2	123	21.9
KBJ-BD	860	106	166	57.8	15	8.67	29.9	16.8
KBJ-AD	787	34.8	234	71.1	6.84	1.6	52.7	22.7
KKH	1200	550	247	258	21	13.6	63.6	43.4
KCN	702	1180	233	272	12.8	16.1	18.1	45.6
Min	353	34.8	166	55.9	6.8	1.6	18.1	16.8
Max	22300	286	843	1030	711	481	209	278
Klongs	**STZ**	**CPF**	**TMP**	**SMZ**	**SMX**	**RTM**	**LCM**	**CAP**
KBL-BD	221	194	75.4	7.62	9.23	ND	15.5	2.11
KBL-AD	65.5	48.0	25.5	3.24	2.66	ND	1.33	1.38
KPK-BD	52.8	30.0	35.0	8.23	10.2	0.64	2.43	7.69
KPK-AD	31.1	81.4	27.1	9.35	11.6	3.82	0.95	7.07
KSS-BD	55.3	56.0	19.1	5.99	4.64	0.68	5.91	2.13
KSS-AD	44.2	36.7	5.46	65.8	16.8	3.18	ND	ND
KBJ-BD	11.0	41.8	4.31	8.2	6.81	4.76	ND	ND
KBJ-AD	34.5	25.9	6.94	21.9	16.9	8.35	ND	ND
KKH	13.0	29.3	8.54	7.16	5.54	10	0.96	ND
KCN	29.9	6.93	16.3	4.27	3.53	ND	0.80	ND
Min	11.00	6.93	4.31	3.24	2.7	0.6	0.95	0.0
Max	221.0	194	75.4	65.8	16.9	10.0	15.5	7.7

Note: Unit in ng/L, ND = not detected, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi, Av = Average, Min = Minimum, Max = Maximum

Table 4.8 Concentrations of pharmaceuticals' residues in six canals in Bangkok during September 2011(Cont.)

Klongs	ENRO	FBD	CTC	ETM	FFN	OTC	TYL
KBL-BD	1.	0.6	ND	ND	ND	ND	ND
KBL-AD	0.5	ND	ND	ND	ND	ND	ND
KPK-BD	0.5	ND	ND	ND	ND	ND	ND
KPK-AD	1.3	0.5	ND	ND	ND	ND	ND
KSS-BD	1.9	0.5	ND	ND	ND	ND	ND
KSS-AD	1.9	ND	ND	ND	ND	ND	ND
KBJ-BD	1.3	ND	ND	ND	ND	ND	ND
KBJ-AD	1.2	0.4	ND	ND	ND	ND	ND
KKH	1.0	0.46	ND	ND	ND	ND	ND
KCN	ND	ND	ND	ND	ND	ND	ND
Min	0.5	0.4	ND	ND	ND	ND	ND
Max	1.9	0.6	ND	ND	ND	ND	ND

Note: Unit in ng/L, ND = not detected, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi, Av = Average, Min = Minimum, Max = Maximum

the four receiving canals as compared to the effluent concentrations. Moreover, most of the pharmaceuticals' residues were detected at higher levels before the discharge points (BD) as compared to after discharge point (AD). The concentrations of almost half of the detected pharmaceuticals' residues in the two non receiving canals (KKH and KCN) were also detected at higher levels as compared to the average effluent concentrations of the five WWTPs.

Similar to June 2011, chlortetracycline erythromycin, florfenicol, oxytetracycline, and tylosin were not detected in any of the canal samples. Fenbendazole had the lowest level (ranging between 0.4 ng/L and 0.6 ng/L, with an average of 0.5 ng/L), followed by enrofloxacin (ranging between 0.5 ng/L and 1.9 ng/L, with an average of 1.2 ng/L). Among the six canals, the average concentrations of chloramphenicol, lincomycin, roxithromycin and sulfamethoxazole, were below 10 ng/L, ranging between 0.6 ng/L and 16.9 ng/L.

4.3.3 Concentrations of Pharmaceuticals' Residues in Six Canals in January 2012

The concentrations of the tested pharmaceuticals' residues in the four receiving canals (before and after discharge point) and two non-receiving canals in Bangkok, in January 2012 are summarized in Table 4.9.

Table 4.9 Concentrations of pharmaceuticals in six canals in Bangkok during January 2012

Klongs	CAF	IBP	MFN	OTC	DCF	ASA	STZ	AAP
KBL-B	932.5	523.0	262.5	0.0	74.9	172.5	55.4	260
KBL-A	847.0	307.0	252.5	0.0	66.1	18.0	42.2	82.1
KPK-B	183.5	95.0	57.6	0.0	14.2	17.5	32.0	7.7
KPK-A	130.0	97.0	93.8	0.0	64.2	14.9	60.5	12
KSS-B	135.5	69.1	99.7	0.0	111.3	21.9	93.9	13.3
KSS-A	117.0	72.3	90.2	0.0	118.5	25.0	118.5	6.6
KBJ-B	191.0	164.0	190.5	0.0	94.3	183.0	49.6	23.7
KBJ-A	73.8	34.6	124.5	413.8	41.7	54.8	37.8	9.81
KKH	211.0	247.0	122.5	260.5	13.7	16.1	20.4	19
KCN	703.0	212.5	121.0	0.0	24.3	31.4	19.4	5.2
Min	73.8	34.6	57.6	0.0	13.7	14.9	19.4	5.2
Max	932.5	523.0	262.5	413.8	118.5	183.0	118.5	260
Klongs	**NPX**	**ATEN**	**CPF**	**TMP**	**SMZ**	**RTM**	**SMX**	**LCM**
KBL-B	114.0	79.3	41.1	29.9	13.2	1.7	4.8	4.9
KBL-A	107.6	48.2	40.9	21.6	10.2	2.5	4.0	2.7
KPK-B	26.7	4.4	0.0	4.1	3.7	3.5	1.7	0.0
KPK-A	47.7	31.1	0.0	13.0	15.2	21.2	9.0	0.7
KSS-B	28.3	44.0	43.1	17.8	15.5	17.5	11.6	0.5
KSS-A	32.9	36.2	53.3	18.9	14.8	19.3	12.2	0.0
KBJ-B	7.2	24.6	76.2	16.1	9.6	11.1	9.0	1.0
KBJ-A	4.6	8.7	25.6	7.2	14.3	5.5	11.9	0.5
KKH	14.2	11.5	0.0	8.8	4.5	9.4	8.9	0.8
KCN	17.4	30.8	0.0	13.2	0.0	5.8	1.4	0.3
Min	4.6	4.4	0.0	4.1	0.0	1.7	1.4	0.0
Max	114.0	79.3	76.2	29.9	15.5	21.2	12.2	4.9

Note: Unit in ng/L, ND = not detected, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi

Table 4.9 Concentrations of pharmaceuticals in six canals in Bangkok during January 2012 (Cont.)

Klongs	ENRO	CAP	FBD	CTC	ETM	FFN	TYL
KBL-B	0.0	1.6	ND	ND	ND	ND	ND
KBL-A	0.0	0.8	ND	ND	ND	ND	ND
KPK-B	0.0	0.0	ND	ND	ND	ND	ND
KPK-A	0.0	0.6	ND	ND	ND	ND	ND
KSS-B	0.0	0.0	ND	ND	ND	ND	ND
KSS-A	0.0	0.0	ND	ND	ND	ND	ND
KBJ-B	6.3	0.0	ND	ND	ND	ND	ND
KBJ-A	2.3	0.0	ND	ND	ND	ND	ND
KKH	0.0	0.0	ND	ND	ND	ND	ND
KCN	0.0	0.6	ND	ND	ND	ND	ND
Min	0.0	0.0	ND	ND	ND	ND	ND
Max	6.3	1.6	ND	ND	ND	ND	ND

Note: Unit in ng/L, ND = not detected, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi, Av = Average, Min = Minimum, Max = Maximum

It can be seen in Table 4.9 that the concentrations of caffeine were found to be at the highest levels, ranging between 73.8 ng/L and 35.4 ng/L, with an average of 352.4 ng/L. This was followed by ibuprofen (ranging between 34.6 ng/L and 523 ng/L, with an average of 182.1 ng/L) and mefenamic acid (ranging between 57.6 ng/L and 262.5 ng/L, with an average of 141.5 ng/L). During this time, the concentrations of all the pharmaceuticals' residues in most of the canals were at lower levels as compared to June 2011 and September 2011. This could be due to the dilution by the high flow conditions in most of the canals (water levels and flows in the river and canals were very high because of severe flooding between September and December 2011 in Bangkok). Interestingly, oxitetracyclin was not found in most of the samples from the WWTPs, canals and river except during this sampling event. This time, it was detected only in 2 canals: KBJ (413.8 ng/L at AD) and KKH (260.5 ng/L). This suggests that other sources, such as surface runoff, could be responsible for the presence of this compound in the canals.

Similar to June 2011and September 2011, majority of the pharmaceuticals' residues were found to be at higher levels in the four receiving canals as compared to

the effluent concentrations. Moreover, most of the pharmaceuticals' residues were detected at higher levels at before discharge points (BD) compared to the after discharge points (AD). Furthermore, the concentrations of almost 31 % of the detected pharmaceuticals in the two non-receiving canals (KKH and KCN) were at higher levels as compared to the average effluent concentrations of the five WWTPs. Similar to June 2011 and September 2011, chlortetracycline, erythromycin, fenbendazole, florfenicol, oxytetracycline and tylosin were absent from all of the canals samples. Trace amounts of enrofloxacin were detected only in the canal KBJ before discharge point (BD) (6.3 ng/L) and after the discharge point (2.3 ng/L). Chloramphenicol had the lowest average level (0.9 ng/L), ranging between 0.6 ng/L and 1.6 ng/L. It was followed by lincomycin, ranging between 0.3 ng/L and 4.9 ng/L with an average of 1.4 ng/L. The average concentrations of roxithromycin and sulfamethoxazole in the six canals were below 10 ng/L, ranging between 1.4 ng/L and 21.2 ng/L.

4.3.4 Comparison of Pharmaceuticals' Residues in Six Canals during the Three Sampling Events

The average concentrations of the 18 detected pharmaceuticals in the 10 samples from six canals during the three time sampling events are summarized in Table 4.10.

As shown in Table 4.10, chlortetracycline, erythromycin, florfenicol, oxytetracycline, and tylosin were absent from all the canal samples during three sampling events. Average concentrations of the detected pharmaceuticals' residues in six canals during the three sampling events ranged between 0.3 ng/L and 7,518.8 ng/L. The seasonal variation might be one of the factors, which causes the differences in the concentrations during the three sampling events. It is noteworthy that, majority of the pharmaceuticals' residues were found at higher levels in four receiving canals as compared to those of the effluent concentrations. Moreover, for more than half the study pharmaceuticals, the concentrations detected in the two non receiving canals (KKH and KCN) were higher than average effluent concentrations of five WWTPs. These observations indicate that WWTPs' effluents were not the only contributors of

Table 4.10 Average pharmaceuticals' residues in six canals during three sampling events in Bangkok

Pharma-ceutical	KRK-BD	KRK-AD	KPK-BD	KPK-AD	KSS-BD	KSS-AD	KBJ-BD	KBJ-AD	KKH*	KCN*
AAP	267.4	435.3	197.1	42.6	178.4	44.0	27.6	98.6	224.6	224.3
ASA	7518.8	295.3	241.2	201.3	270.0	180.7	407.9	352.6	663.4	3027.8
ATEN	101.3	56.2	78.0	49.1	44.8	23.0	21.5	21.6	27.7	62.8
CAF	1105.5	569.7	1614.2	1445.7	404.7	90.5	129.2	101.5	361.0	1541
CAP	1.5	1.3	4.2	7.1	2.1	ND	ND	ND	ND	ND
CPF	194.0	48.0	89.0	88.8	54.3	51.9	56.6	29.2	36.8	9.4
DCF	102.1	83.2	74.3	70.1	97.9	121.2	81.8	49.1	38.2	34.0
ENRO	1.1	0.5	0.5	1.3	1.9	1.9	3.2	1.7	1.0	ND
FBD	0.5	0.7	ND	0.5	0.4	0.3	0.3	0.4	0.5	1.6
IBP	402.1	147.7	419.0	246.3	172.6	59.6	93.8	81.2	267.0	368.8
LCM	6.9	1.9	1.1	0.8	3.2	ND	ND	0.6	1.3	3.3
MFN	438.9	359.3	356.2	298.2	291.9	214.7	190.4	195.2	219.8	347.3
NPX	184.4	69.9	99.2	78.6	58.2	45.8	20.5	5.7	20.5	47.2
OTC	ND	ND	ND	ND	ND	ND	ND	413.8	260.5	ND
RTM	5.8	3.5	2.1	12.5	7.1	9.1	8.3	4.7	6.6	5.8
SMX	7.7	12.0	13.9	10.9	35.7	51.9	23.2	18.1	7.6	4.3
SMZ	5.8	5.0	4.9	9.1	19.3	29.2	15.0	10.3	5.4	3.2

Note: Unit in ng/L, ND = not detected, * samples were taken before the intersection with another canal or river, KBL = Klong Bang Lampho, KPK = Klong Phadung Krunkasem, KSS = Klong Sam Sen, KBJ = Klong Bang Jak, KKH = Klong Kao Hong and KCN = Klong Chon Nonsi

these pharmaceuticals' residues. Potential contribution of non-point sources or direct releases from the household without treatment might be possible and warrants further investigation.

Acetylsalicylic acid was detected at the highest concentrations in canal waters, ranging between 14.85 ng/L and 22,300 ng/L (average of 1,355 ng/L). Significant seasonal variation were observed for ASA with up to four orders of magnitude difference between September 2011(22,300 ng/L) and January 2012 (17.5 ng/L). The highest level of ASA in September 2011 sampling event (22,300 ng/L) was 1.6 times higher than the concentration detected in the influent of RK WWTP and 8.4 times higher than the effluent of the same plant that discharged into canal KBL. The second highest concentration was detected for CAF (ranging between 21.4 ng/L

and 2,860 ng/, average of 758.56 ng/L) followed by mefenamic acid (ranging between 260.5 ng/L and 413.8 ng/L, with an overall average of 337.2 ng/L) and ibuprofen (ranging between 59.6 ng/L and 419 ng/L, with an overall average of 225.8 ng/L).

The overall average concentration of fenbendazole was found to be at the lowest level (ranging between 0.3 ng/L and 1.6 ng/L, with an average of 0.6 ng/L) followed by enrofloxacin (ranging between 0.5ng/L and 3.2 ng/L, with an overall average of 1.5 ng/L), and lincomycin (ranging between 0.6 ng/L and 6.9 ng/L, with an overall average of 2.4 ng/L). Interestingly, RTM was not detected in any influent samples during June and September 2011, however, it was present in most of the canals samples obtained from even before WWTPs' discharge points, ranging from 0.64 – 9.9 ng/L (average of 3.8 ng/L). Oxytetracycline was found only one time in the KBJ canal (413.8 ng/L) and the KKH canal (260.5 ng/L) during January 2012 sampling event (it was not detected in any effluent sample throughout the three sampling events). This again suggests that other sources could be responsible for the presence of these compounds in the receiving canals.

4.4 Concentrations of Pharmaceuticals' Residues in Chao Phraya River in Bangkok

Chao Phraya River is the secondary downstream receiving water body for all the five WWTPs, except the CN WWTP, that directly discharges into it. Ambient water was collected from four locations in Chao Phraya River, i.e., Rama Seven Bridge (1-R7B), Wat Maha Raj at Sanam Luang (2-SL), Wat Yannawa at Chalerm Krung (3-CK) and Bangkok Export Office at Klong Toey (4-KT). The concentrations of the pharmaceuticals' residues in the Chao Phraya River during the three sampling events are presented in the following sections.

4.4.1 Concentrations of Pharmaceuticals' Residues in Chao Phraya River in June 2011

The concentrations of the tested pharmaceuticals' residues in the Chao Phraya River at four different locations in June 2011 are presented in Table 4.11 and Fig. 4.7.

Table 4.11 Concentrations of pharmaceuticals' residues in Chao Phraya River in Bangkok during June 2011

River Points	CAF	ASA	AAP	IBP	MFN	NPX	DCF	ATEN
1-R7B	53.8	199	134	9.71	16.2	ND	6.28	1.74
2-SL	258	79.3	ND	30.2	28.2	9.54	9.91	4.46
3-CK	227	88.4	53.1	49.4	36.2	41.3	8.65	2.88
4-KT	178	100	66.8	36.5	40.4	6.85	11.5	3.63
Min	53.8	79.3	53.1	9.7	16.2	6.9	6.3	1.7
Max	258.0	199.0	134.0	49.4	40.4	41.3	11.5	4.5
River Points	**SMX**	**TMP**	**RTM**	**CPF**	**SMZ**	**STZ**	**CAP**	**ENRO**
1-R7B	ND	1.24	ND	ND	ND	ND	ND	ND
2-SL	1.58	1.67	0.67	ND	ND	ND	ND	ND
3-CK	1.57	ND	0.90	ND	ND	ND	ND	ND
4-KT	1.92	ND	0.59	ND	ND	ND	ND	ND
Min	1.6	1.2	0.6	ND	ND	ND	ND	ND
Max	1.9	1.7	0.9	ND	ND	ND	ND	ND

River Points	FBD	LCM	CTC	ETM	FFN	OTC	TYL
1-R7B	ND	ND	ND	ND	ND	ND	ND
2-SL	ND	ND	ND	ND	ND	ND	ND
3-CK	ND	ND	ND	ND	ND	ND	ND
4-KT	ND	ND	ND	ND	ND	ND	ND

Note: Unit in ng/L, ND = not detected, 1-R7B = Rama Seven Bridge, 2-SL= WatMaha Raj, SanamLuang 3-CK = WatYannawa, Chalerm Krung and Bangkok Export Office, 4-KT = KlongThoi, Av = Average, Min = Minimum, Max = Maximum

It can be seen in Table 4.11, that more than 50% of the tested pharmaceuticals (ciprofloxacin, sulfamethazine, sulfathiazole, chloramphenicol, enrofloxacin, fenbendazole, lincomycin, chlortetracycline, erythromycin, florfenicol, oxytetracycline and tylosin) were not detected in any of the river samples.

Concentrations of the 11 detected pharmaceuticals' residues at the four sampling points in the river during June 2011 sampling event, ranged between 0.6

ng/L and 258 ng/L. Caffeine (ranging between 53.8 ng/L and 58 ng/L, with an average of 179 ng/L), acetylsalicylic acid (ranging between 79.3 ng/L and 199 ng/L, with an average of 116.7ng/L) and acetaminophen (ranging between 53.1 ng/L and 134 ng/L, with an average of 63.5 ng/L) were the top three highest levels. Highest level of caffeine could be explained by the reason stated in section 4.1.1. Trace amounts (averaging below 10 ng/L) of diclofenac, atenolol, sulfamethoxazole, trimethoprim and roxithromycin were detected in the river samples and ranged between 0.6 ng/L and 11.5 ng/L.

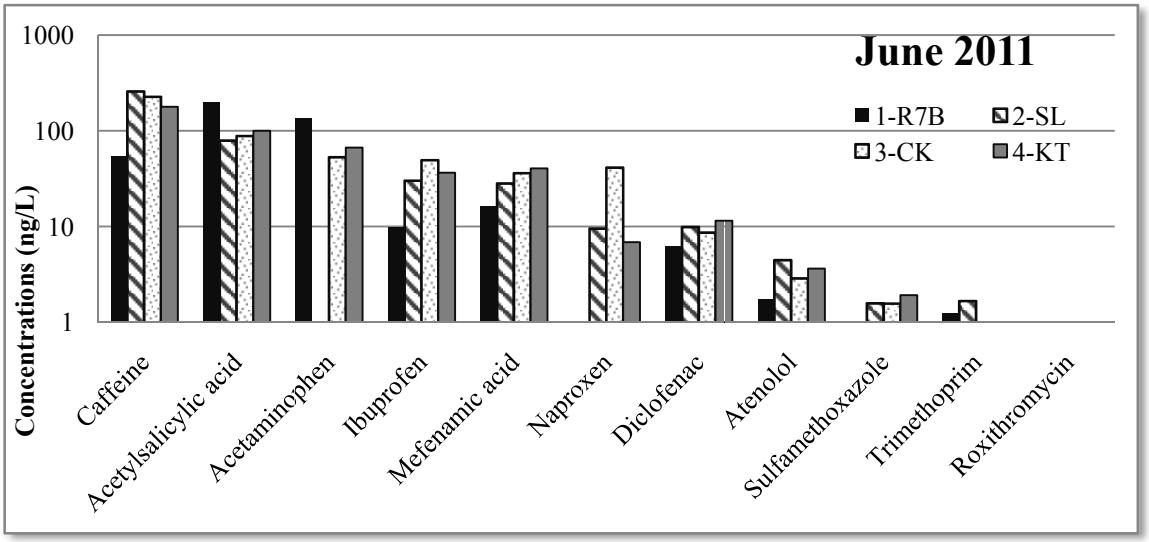

Fig. 4.11 pharmaceuticals' residues in Chao Phraya River in June 2011

4.4.2 Concentrations of Pharmaceuticals' Residues in Chao Phraya River in September 2011

The concentrations of the pharmaceuticals' residues detected in the Chao Phraya River at the four different locations in September 2011 are summarized in Table 4.12 and Fig. 4.8.

It can be seen in Table 4.12, that similar to June 2011, chloramphenicol, enrofloxacin, fenbendazole, lincomycin, chlortetracycline, erythromycin, florfenicol, oxytetracycline and tylosin were absent from all river samples. On an average, acetylsalicylic acid was found to be at the highest level ranging from 402 ng/L to 1100 ng/L, with an average of 764.8 ng/L. It is noteworthy that the levels of acetylsalicylic acid at all the

four points were higher than the average effluent concentration (356 ng/L) of the five WWTPs. This observation deserves our attention as other sources could also be responsible for the presence of this pharmaceutical in the river water. The second highest level was found for caffeine (ranging between 35.5 ng/L and 117 ng/L, with an average of 65.6 ng/L), followed by ibuprofen (ranging between 7.9 ng/L and 25.7 ng/L, with an average of 16.4 ng/L). Atenolol, diclofenac, enrofloxacin, naproxen, roxithromycin, sulfamethoxazole, sulfamethazine, sulfathiazole and trimethoprim were at below 10 ng/L and ranged from 0.5 ng/L to 8.9 ng/L. Enrofloxacin (ranging between 0.7 ng/L and 1.9 ng/L, with an average of 1.3 ng/L), sulfamethazine (ranging between 2.6 ng/L and 3.5 ng/L, with an average of 2.9 ng/L) and sulfathiazole (ranging between 2.3 ng/L and 2.8 ng/L, with an average of 2.4 ng/L) were at the

Table 4.12 Concentrations of pharmaceuticals' residues in Chao Phraya River in Bangkok during September 2011

River Points	ASA	CAF	IBP	CPF	MFN	AAP	DCF	SMZ
1-R7B	639	35.5	7.9	47.7	3.6	6.1	4.4	3.0
2-SL	918	36.7	12.8	ND	10.4	16.0	5.4	2.6
3-CK	1100	73.2	19.0	ND	11.2	6.0	6.8	3.5
4-KT	402	117	25.7	ND	18.0	7.1	8.9	2.6
Min	402	35.5	7.9	-	3.6	6.0	4.4	2.6
Max	1100	117	25.7	47.7	18.0	16.0	8.9	3.5
River Points	**RTM**	**NPX**	**STZ**	**ENRO**	**TMP**	**ATEN**	**SMX**	**CAP**
1-R7B	1.8	0.8	2.3	1.7	0.5	1.2	0.5	ND
2-SL	1.1	2.0	2.3	0.7	0.8	0.9	0.7	ND
3-CK	2.4	1.5	ND	1.9	0.7	0.8	0.5	ND
4-KT	5.4	3.2	2.8	1.0	2.7	1.1	0.8	ND
Min	1.1	0.8	2.3	0.7	0.5	0.8	0.5	ND
Max	5.4	3.2	2.8	1.9	2.7	1.2	0.8	ND

River Points	FBD	LCM	CTC	ETM	FFN	OTC	TYL
1-R7B	ND	ND	ND	ND	ND	ND	ND
2-SL	ND	ND	ND	ND	ND	ND	ND
3-CK	ND	ND	ND	ND	ND	ND	ND
4-KT	ND	ND	ND	ND	ND	ND	ND

Note: Unit in ng/L, ND = not detected, 1-R7B = Rama Seven Bridge, 2-SL= WatMaha Raj, SanamLuang, 3-CK = WatYannawa, Chalerm Krung and 4-KT = Bangkok Export Office, KlongThoi, Av = Average, Min = Minimum, Max = Maximum

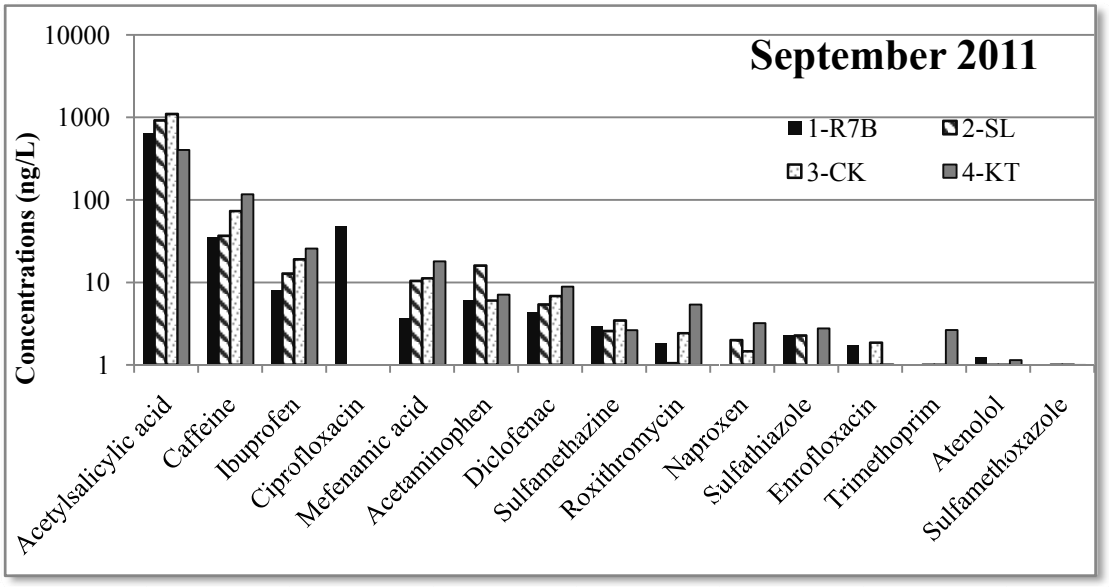

Fig. 4.12 Average concentrations of pharmaceuticals' residues in Chao Phraya River in September 2011

bottom three levels. Ciprofloxacin was detected only at one point: 1-R7B (47.7 ng/L). Enrofloxacin, sulfamethazine, sulfathiazole and ciprofloxacin were not found at any location during June 2011 sampling event.

4.4.3 Concentrations of Pharmaceuticals' Residues in Chao Phraya River in January 2012

The concentrations of tested pharmaceuticals' residues in the Chao Phraya River at four different locations during January 2012 are summarized in Table 4.13 and Fig. 4.9. During this sampling event, the concentrations for all of the pharmaceuticals' residues were at lower levels as compared to June 2011 and September 2011.

It can be seen in Table 4.11, that similar to the last two sampling events, ciprofloxacin, enrofloxacin, fenbendazole, lincomycin, chlortetracycline, erythromycin, florfenicol, oxytetracycline and tylosin were not detected in any of the river samples. Similar to June 2011, the average concentrations for caffeine (ranging between 70.9 ng/L and 179 ng/L, with an average of 122.9 ng/L) and acetylsalicylic acid (ranging between 23.2 ng/L and 91.5 ng/L, with an average of 56.3 ng/L) were

Table 4.13 Concentrations of pharmaceuticals' residues in Chao Phraya River in Bangkok during January 2012

River Points	CAF	ASA	IBP	MFN	DCF	AAP	NPX	ATEN
1-R7B	148	23.2	33.1	21.8	10.3	14.5	3.2	3.0
2-SL	93.6	85.7	24.5	16.3	13.3	8.5	3.3	1.8
3-CK	179	91.5	43.9	24.5	19.1	4.8	5.2	3.9
4-KT	70.9	24.8	38.7	21.3	7.9	5.1	4.2	2.9
Min	70.9	23.2	24.5	16.3	7.9	4.8	3.2	1.8
Max	179.0	91.5	43.9	24.5	19.1	14.5	5.2	3.9
River Points	**AMZ**	**STZ**	**TMP**	**RTM**	**SMX**	**CAP**	**CPF**	**ENRO**
1-R7B	5.3	0	1.6	1.3	ND	ND	ND	ND
2-SL	2.3	4.9	1.1	0.8	1.3	ND	ND	ND
3-CK	2.7	5	2.3	2.6	1.9	1.2	ND	ND
4-KT	ND	ND	2.0	2.0	0.7	ND	ND	ND
Min	2.3	4.9	1.1	0.8	0.7	1.2	ND	ND
Max	5.3	5.0	2.3	2.6	1.9	1.2	ND	ND
River Points	**FBD**	**LCM**	**CTC**	**ETM**	**FFN**	**OTC**	**TYL**	
1-R7B	ND	ND	ND	ND	ND	ND	ND	
2-SL	ND	ND	ND	ND	ND	ND	ND	
3-CK	ND	ND	ND	ND	ND	ND	ND	
4-KT	ND	ND	ND	ND	ND	ND	ND	

Note: Unit in ng/L, ND = not detected, 1-R7B = Rama Seven Bridge, 2-SL= WatMaha Raj, SanamLuang, 3-CK = WatYannawa, Chalerm Krung and Bangkok Export Office, 4-KT = KlongThoi, Av = Average, Min = Minimum, Max = Maximum

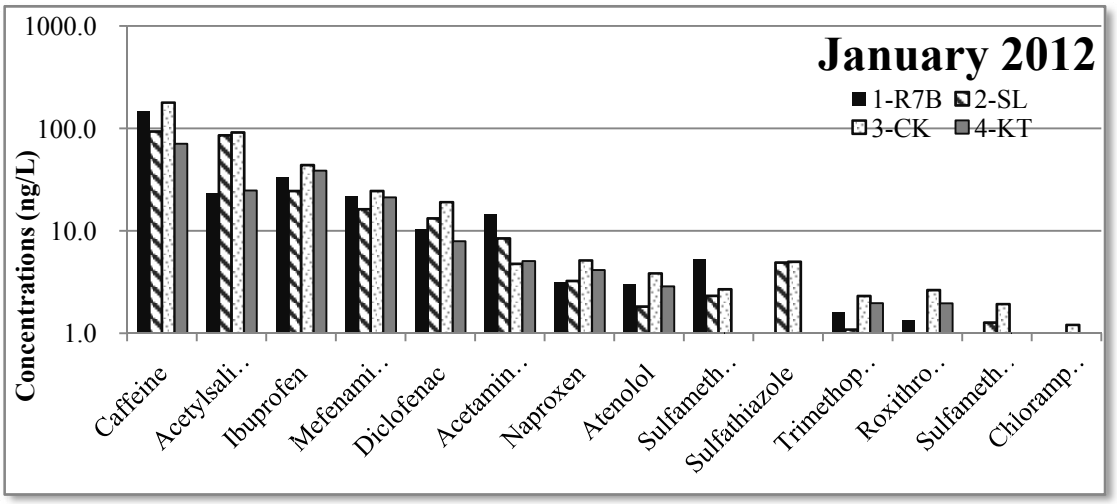

Fig. 4.13 Average concentrations of pharmaceuticals' residues Chao Phraya River in January 2012

found to be at the top two levels in all river samples. These were followed by ibuprofen (ranging between 24.5 ng/L and 43.9 ng/L, with an average of 35 ng/L) and mefenamic acid (ranging between 16.3 ng/L and 24.5 ng/L, with an average of 21 ng/L). Sulfamethazine (ranging between 2.3 ng/L and 5.3 ng/L, with an average of 3.4 ng/L) and sulfathiazole (ranging between 4.9 ng/L and 5 ng/L, with an average of 5 ng/L) were found at moderate levels during this time. However, these two compounds were found at lower levels during September 2011 sampling event (Sulfamethazine: 2.9 ng/L and sulfathiazole: 2.4 ng/L) and were not found during the June 2011. Sulfamethoxazole (ranging between 0.7 ng/L and 1.9 ng/L, with an averages of 1.3 ng/L), roxithromycin (ranging between 0.8 ng/L and 2.6 ng/L, with an averages of 1.7 ng/L), and trimethoprim (ranging between 1.1 ng/L and 2.3 ng/L, with an averages of 1.7 ng/L) were at bottom three levels in all the river samples. Interestingly, chloramphenicol was absent from all of the river samples during the June 2011 and September 2011. This time, trace amount of chloramphenicol (1.2 ng/L) was found only at one point: 3-CK. These observations suggest that the dilutions due to the high seasonal flow could be one of the reasons responsible for the low concentrations of the pharmaceuticals' residues in the river during this sampling event.

4.4.4 Comparison of Pharmaceuticals' Residues in Chao Phraya River during the Three Sampling Events

The average concentrations of the pharmaceuticals' residues detected at four different points in the Chao Phraya River during the three sampling events are summarized in Table 4.14 and Fig. 4.10.

As shown in Fig. 4.14, pharmaceuticals' residues at the four sampling locations in the river ranged between 0.47 and 1,100 ng/L in three sampling events. Similar to the canals, the pharmaceuticals in the river were often found to be at higher levels than in the effluents. Among the detected pharmaceuticals in river samples, average concentration of acetylsalicylic acid was found to be at the highest, ranging between 23 ng/L and 1,100 ng/L (average of 312.6 ng/L) in all the three sampling events. The concentrations of acetylsalicylic acid in receiving water bodies during the

Table 4.14 Average concentrations of pharmaceuticals in Chao Phraya River in Bangkok during the three sampling events in Bangkok

Pharmaceuticals	Range	1-R7B	2-SL	3-CK	4-KT
Acetylsalicylic acid	23.2 - 1100.0	287.1	361	426.6	175.6
Caffeine	35.5 - 258.0	79.1	129.4	159.7	122
Acetaminophen	4.8 - 134.0	51.5	12.2	21.3	26.3
Ciprofloxacin	47.7	47.7	ND	ND	ND
Ibuprofen	7.9 - 49.4	16.9	22.5	37.4	33.6
Mefenamic acid	3.6 - 40.4	13.9	18.3	24	26.6
Diclofenac	4.4 - 19.1	7	9.5	11.5	9.4
Sulfamethazine	2.3 - 5.3	2.7	1.6	2	1.3
Atenolol	0.8 - 4.5	2	2.4	2.5	2.5
Naproxen	0.8 - 41.3	2	4.9	16	4.7
Roxithromycin	0.6 - 5.4	1.6	0.8	2	2.6
Sulfathiazole	2.3 - 5.0	1.2	2.4	2.5	1.4
Trimethoprim	0.5 - 2.7	1.1	1.2	1.5	2.3
Enrofloxacin	0.7 - 1.9	0.9	0.4	0.9	0.5
Sulfamethoxazole	0.5 - 1.9	0.5	1.2	1.3	1.2
Chloramphenicol	0.3 - 1.2	ND	ND	0.6	ND

Note: Unit in ng/L, ND = not detected, 1-R7B = Rama Seven Bridge, 2-SL= WatMaha Raj, SanamLuang, 3-CK = WatYannawa, ChalermKrung and 4-KT = Bangkok Export Office, KlongThoi.

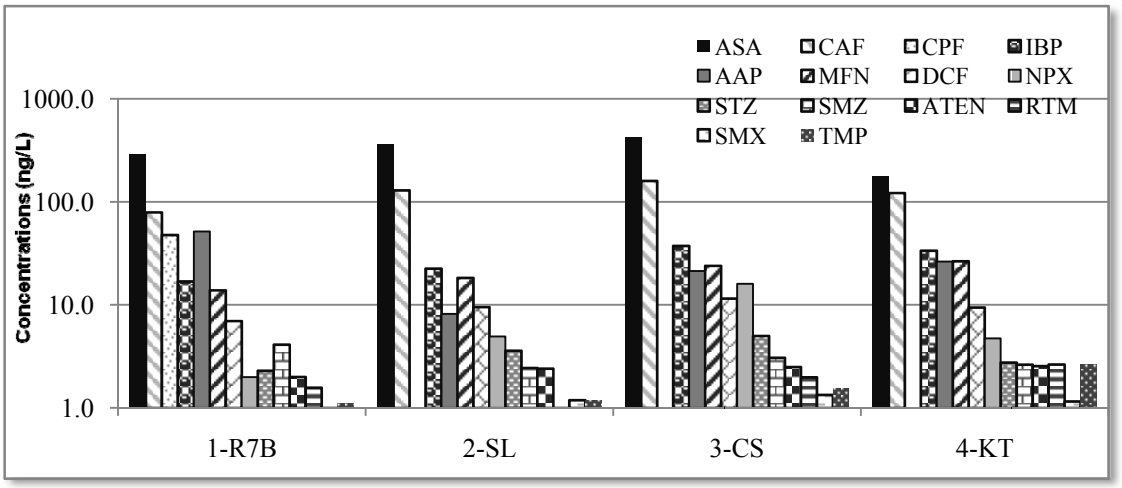

Fig. 4.14 Average concentrations of pharmaceuticals in Chao Phraya River during the three sampling events

previous study conducted in Bangkok (ranging between 12.3 ng/L and 1,140 ng/L, average: 174 ng/L) were similar to present study (Li, 1010).

Apart from acetylsalicylic acid, five pharmaceuticals such as atenolol (average: 2.36 ng/L, ranged between 0.8 and 4.5 ng/L), caffeine (average:122.6 ng/L, ranged between 35.5 and 258 ng/L), diclofenac (average: 9.36 ng/L, ranged between 4.4 and 19.1 ng/L), ibuprofen (average: 27.62 ng/L, ranged between 7.9 and 49.4 ng/L) and mefenamic acid (average: 20.7 ng/L, ranged between 3.6 and 40.5 ng/L) were detected consistently at all locations in three sampling events. The concentrations of atenolol in Chao Phraya River (ranging between 0.8 and 4.5 ng/L) appeared to be lower than the reported levels in two other countries: Sweden (ranging between nd and 60 ng/L) and South Korea (ranging between nd and 690 ng/L) (Bendz, et al., 2005, Kim, et al., 2009). In a previous study conducted in Bangkok (Li, 2010), the maximum concentrations of caffeine (13,600 ng/L), diclofenac (102 ng/L), ibuprofen (2050 ng/L) and mefenamic acid (158 ng/L) were found to be at much higher levels in receiving waters as compared to present study. Similarly, in another study conducted in USA, the maximum concentration of caffeine in surface waters (6000 ng/L) was found to be much higher as compared to present study (258 ng/L) (Kolpin, et al., 2002). Whereas, concentrations of caffeine in surface waters of South Korea, were reported to range between 2.9 and 373 ng/L (Kim, et al., 2007, Choi, et al., 2008, and Sim, et al., 2010). The maximum concentration of diclofenac in river water in present study (19.1 ng/L) appeared to be lower than the reported maximum levels in Canada (21 ng/L), Sweden (120 ng/L) and Taiwan (56.5 n/L); and higher than in South Korea (6.8 ng/L) (Bendz, et al., 2005, Chan et al., 2006, Kim, et al., 2007 and Lin, et al., 2009). Maximum concentration of ibuprofen in river water in present study (49.4 ng/L) appeared to be lower than the reported levels in some other countries: South Korea (414 ng/L), Taiwan (4350 ng/L), China (416 ng/L) and Sweden (220 ng/L); but higher than in Canada (23 ng/L) (Bendz, et al., 2005, Chan et al., 2006, Kim, et al., 2009, Lin et al., 2009 and Wong et al., 2010). Similarly, the maximum concentration of mefenamic acid in river water in present study (40.5 ng/L) appeared to be lower than the reported level in South Korea (326 ng/L) (Kim, et al 2009). Naproxen, roxithromycin, sulfamethoxazole, sulfamethazine, sulfathiazole and

trimethoprim were detected only a few times, at lower levels (generally less than 10 ng/L except for naproxen - 41.3 ng/L at sampling point 3-CK in June 2011), with an average of 7.35, 1.78, 1.16, 3.13, 3.45 and 1.22 ng/L, respectively. Ciprofloxacin was absent in almost all river samples except once detected at the first sampling point (1-R7B) during September 2011. In a previous study conducted in Bangkok (Li, 2010), the maximum concentration of ciprofloxacin in receiving water (123 ng/L) was found to be much higher than in the present study (47.7 ng/L). The maximum concentrations of ciprofloxacin in surface waters in USA and Canada were found to be at 30 ng/L and 78 ng/L, respectively (Kolpin, et al., 2002 and Chan et al., 2006).

4.5 Concentrations of Pharmaceuticals in Sewage Treatment Plants (STPs) in Seoul during March 2011

The Wastewater samples were collected from the influents, aeration tank and effluents of four selected sewage treatment plants (STPs) (Jung Rang, NanJi, SeoNam and TanCheon) in Seoul, South Korea during March 2011. The concentrations of the tested pharmaceuticals in the influents, aeration tank and effluents are shown in Table 4.15. Chlorotetracyclin and tylosin were not detected in any of the influent, aeration tank and effluent samples. This reflects the low usage of these two drugs in Seoul, South Korea.

Influent Concentrations

Among the influent samples, the concentrations of the detected pharmaceuticals ranged from 0.1 ng/L to 85,000 ng/L. Based upon the average concentrations of the four STP's, the highest level was found for acetylsalicylic acid ranging between 56,300 ng/L and 85,300 ng/L, with an average of 70,175 ng/L. Acetylsalicylic acid was found to be at the highest level (85,300 ng/L) in JR STP. The average level of acetylsalicylic acid in the present study appeared to be 20 times higher than a previously reported value (3,505 ng/L) during May 2009 in Seoul (Li, 2010). Ibuprofen was found to be at the second highest level, ranging between 4,310

ng/L and 5,190 ng/L, with an average of 4,667.5 ng/L, followed by naproxen (ranging between 2,400 ng/L and 3,430 ng/L with an average of 2,905 ng/L) and caffeine

Table 4.15 Concentrations of pharmaceuticals in four sewage treatment plants (STPs) in Seoul, South Korea in March 2011

STPs	Acetylsalicylic Acid			Ibuprofen			Naproxen		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	56,300	352	76.6	4,810	150.0	36.0	2,400	203.0	199.0
JR	85,000	2,200	66.7	5,190	111.0	30.5	3,430	117.0	153.0
NJ	70,600	2,820	279	4,290	151.0	40.1	2,920	112.0	130.0
SN	68,800	4,310	44.8	4,380	141.0	108.0	2,870	283.0	165.0
Max	85,300	4,310	76.6	5,190	151.0	108.0	3,430	283.0	199.0
Min.	56,300	352	44.8	4,380	111.0	30.5	2,400	112.0	130.0

STPs	Caffeine			Acetaminophen			Mefenamic Acid		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	1,390	15.0	25.6	1,530	6.3	2.8	683.0	1,170	359.0
JR	1,290	5.6	7.7	2,110	2.5	3.4	647.0	785	397.0
NJ	2,750	9.4	118.0	1,180	8.7	24.0	399.0	1,360	713.0
SN	3,020	11.5	92.3	1,430	10.1	6.8	472.0	1,430	484.0
Max	3,020	15.0	118.0	2,110	10.1	24.0	683.0	1,430	713.0
Min.	1,290	5.6	7.7	1,430	2.5	2.8	399.0	785	359.0

STPs	Ciprofloxacin			Atenolol			Lincomycin		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	445.0	299.0	83.9	99.3	13.6	41.9	94.9	21.8	44.8
JR	487.0	286.0	53.6	275.0	21.7	59.4	155.0	19.6	4.7
NJ	247.0	64.2	282.0	135.0	62.8	179.0	201.0	100.0	180.0
SN	271.0	155.0	46.7	166.0	57.9	48.7	203.0	88.7	51.5
Max	487.0	299.0	282.0	275.0	62.8	179.0	203.0	100.0	180.0
Min.	271.0	64.2	46.7	99.3	13.6	41.9	94.9	19.6	4.7

Note: JR = JungRang, TC = TanCheon, NJ = NanJi, SN = SeoNam, Inf. = Influent, A. Tank = Aeration Tank, Eff. = Effluent, Av = Average, Min = Minimum, Max = Maximum

Table 4.15 Concentrations of pharmaceuticals in four sewage treatment plants (STPs) in Seoul, South Korea in March 2011(Cont.)

STPs	Diclofenac			Oxitetracyclin			Roxithromycin		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	149.0	193.0	116.0	64.9	31.3	ND	103.0	137.0	173.0
JR	156.0	195.0	101.0	226.0	18.2	ND	91.2	109.0	111.0
NJ	136.0	280.0	164.0	71.3	ND	36.3	81.1	174.0	242.0
SN	120.0	187.0	67.9	96.9	37.9	44.0	133.0	98.2	119.0
Max	156.0	280.0	164.0	226.0	37.9	44.0	133.0	174.0	242.0
Min.	120.0	187.0	67.9	64.9	18.2	ND	81.1	98.2	111.0

STPs	Trimethoprim			Sulfamethoxazole			Chlorampenicol		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	101.0	57.3	49.4	125.0	9.6	9.2	86.9	6.7	5.6
JR	96.4	59.1	46.1	75.7	11.6	8.2	73.6	6.7	4.2
NJ	87.7	73.7	58.1	63.3	14.8	15.5	22.7	22.7	14.9
SN	83.0	83.3	54.6	81.3	25.5	28.7	47.0	20.5	3.6
Max	101.0	83.3	58.1	125.0	25.5	28.7	86.9	22.7	14.9
Min.	83.0	57.3	46.1	63.3	9.6	8.2	47.0	6.7	3.6

STPs	Enrofloxacin			Florfenicol			Sulfathiazole		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	4.7	4.4	2.3	4.5	1.7	0.8	3.0	14.6	ND
JR	5.0	1.1	1.2	3.0	0.6	2.7	4.9	1.5	ND
NJ	ND	4.7	8.8	ND	1.0	0.6	2.1	8.7	4.8
SN	6.3	0.6	2.7	3.2	1.3	0.7	ND	ND	ND
Max	6.3	4.4	8.8	4.5	1.7	2.7	4.9	14.6	4.8
Min.	ND	0.6	1.2	3.0	0.6	0.6	ND	ND	ND

Note: JR = JungRang, TC = TanCheon, NJ = NanJi, SN = SeoNam, Inf. = Influent, A. Tank = Aeration Tank, Eff. = Effluent, Av = Average, Min = Minimum, Max = Maximum

Table 4.15 Concentrations of pharmaceuticals in four sewage treatment plants (STPs) in Seoul, South Korea in March 2011(Cont.)

STPs	Sulfamethazine			Fenbendazole			Erythromycin		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	3.5	26.9	ND	0.7	0.4	0.1	ND	2.0	0.8
JR	2.0	3.2	ND	0.5	ND	0.3	0.3	0.9	0.4
NJ	3.4	4.9	3.9	ND	0.3	0.2	ND	2.7	1.9
SN	3.1	4.1	1.7	ND	0.5	0.3	0.1	1.7	0.5
Max	3.5	26.9	3.9	0.7	0.5	0.3	0.3	2.7	1.9
Min.	2.0	3.2	ND	ND	0.4	0.1	0.1	0.9	0.5

STPs	Chlorotetracyclin			Tylosin		
	Inf.	A. Tank	Eff.	Inf.	A. Tank	Eff.
TC	ND	ND	ND	ND	ND	ND
JR	ND	ND	ND	ND	ND	ND
NJ	ND	ND	ND	ND	ND	ND
SN	ND	ND	ND	ND	ND	ND

Note: JR = JungRang, TC = TanCheon, NJ = NanJi, SN = SeoNam, Inf. = Influent, A. Tank = Aeration Tank, Eff. = Effluent, Av = Average, Min = Minimum, Max = Maximum

(ranging between 1,290 ng/L and 3,020 ng/L with an average of 2,112.5 ng/L). This reflects the popular usage of these four drugs in Seoul, South Korea. Similar observation was reported based on production and consumption data for South Korea (Sim et al., 2010). Interestingly, caffeine was detected at the highest level in the pervious study (21,550 ng/L) (Li, 2010). This was 10.2 times higher as compared to the present study (2,112.5 ng/L). On the other hand, the average levels of ibuprofen and naproxen were lower than before (1,375 ng/L and 706.5 ng/L, respectively).

Among all influent samples, erythromycin was found to be at the lowest average level (ranging between 0.1 to 0.3 ng/L, with an average of 0.2 ng/L), followed by fenbendazole (ranging between 0.5 ng/L and 0.7 ng/L, with an average of 0.6 ng/L) and sulfamethoxazole (ranging between 2 ng/L and 3.5 ng/L with an average of 3 ng/L). The average levels of sulfathiazole, florfenicol and enrofloxacin were found to be below 10 ng/L, ranging between 2.1 ng/L and 6.3 ng/L. Erythromycin was at the

second lowest level (average: 3.99 ng/L) in the previous study, but had higher value as compared to the present study. Sulfamethoxazole, having similar average concentration (2.7ng/L) as in this study, was at the middle position among all the 17 detected pharmaceuticals in the previous study (Li, 2010).

Aeration tank Concentrations

Among aeration tank samples of four STPs, concentrations of the detected pharmaceuticals ranged from 0.3 ng/L to 4,310 ng/L. Acetylsalicylic acid was found at the highest average level ranging between 352 ng/L and 4,310 ng/L, with an average of 2,420.5 ng/L, followed by mefenamic acid (ranging between 785 ng/L to 1,430 ng/L, average: 1,186.3 ng/L) and caffeine (ranging between 155 ng/L and 299 ng/L, average: 255.5 ng/L). Among all the detected 21 pharmaceuticals, the bottom three levels were found for fenbendazole (ranging between: 0.3 ng/L and 0.5 ng/L, average: 0.4 ng/L), florfenicol (ranging between: 0.6 ng/L and 1.7 ng/L, average: 1.1 ng/L) and erythromycin (ranging between: 0.9 ng/L and 2.7 ng/L, average: 1.8 ng/L) in the four STPs.

Effluent Concentrations

As shown in Table 4.15, the concentrations of the detected 21 pharmaceuticals in effluent samples of four STPs, ranged between 0.1 ng/L and 713 ng/L. Mefenamic acid was detected to be at the highest level ranging between 359 ng/L and 713 ng/L with an average of 488.3ng/L. This indicated towards its poor removal (11%) during the treatment process. The second highest level was found for naproxen (ranging between 130 - 199 ng/L with an average of 161.8 ng/L), followed by roxithromycin (ranging between 111ng/L and 242 ng/L, with an average of 152.3 ng/L), and acetylsalicylic acid (ranging between 44.80 - 279 ng/L, with an average of 116.78 ng/L). Acetylsalicylic acid had the highest removal (99.8%). However, in a previous study conducted in May 2009 (Li, 2010) the levels of mefenamic acid was found at 10^{th} position (103.10 ng/L), naproxen at 5^{th} position (45.75 ng/L), roxithromycin at 7^{th} position (122.00 ng/L) and acetylsalicylic acid at 3^{th} position (50.05 ng/L). Concentrations of these pharmaceuticals (except roxithromycin) were much lower than this study. Interestingly, during the previous study, similar to

influent samples, the highest average concentration was found for caffeine (average: 2,226.5 ng/L). This was 36.6 times higher as compared to the present study (average: 60.9 ng/L).

Similar to the aeration tank samples of four STP's, the bottom two levels were found for fenbendazole (ranging between 0.1 ng/L and 0.3 ng/L, average: 0.2 ng/L) and erythromycin (ranging between 0.4 ng/L and 1.9 ng/L, average: 0.89 ng/L). These were followed by florfenicol, ranging between 0.6 ng/L and 2.7 ng/L, with an average of 1.2 ng/L. However, in previous study, florfenicol was absent from all the effluent samples and erythromycin was at the third bottom level (average: 4.3 ng/L), and had higher value as compared to the present study.

4.6 Removal of Pharmaceuticals in the Four Sewage Treatment Plants (STPs) in Seoul, South Korea

The Removal efficiencies of the four sewage treatment plants (STPs) for the detected pharmaceuticals are shown in Table 4.16 and the average removal efficiencies of the pharmaceuticals are shown in Fig.4.11.

As shown in Table 4.16 and Fig 4.11, on an averages, all of the STPs had very high efficiencies (ranging between 91.7% and 99.9%) for the removal of acetylsalicylic acid (average: 99.8 %), acetaminophen (average: 99.3 %), ibuprofen (average: 98.8 %), caffeine (average: 97.6 %) and naproxen (average: 94.3 %). This indicates that these pharmaceuticals can be effectively removed through the activated sludge treatment (AST) process. Moderate to high removal (ranging between: 64.7 % and 92.7 %) were found for ciprofloxacin (average: 81.7 %) and sulfamethoxazole (average: 80.5%). However, in the previous study, only acetaminophen (average: 98.9 %), acetylsalicylic acid (average: 98 %), and caffeine (average: 90.8%) were removed above 90 %, and ibuprofen, naproxen and ciprofloxacin were removed at 81 %, 75 %, and 61 % respectively. Interestingly, sulfamethoxazole was at higher concentrations in effluents of all the STPs during last study.

Table 4.16 Removal of detected pharmaceuticals in the sewage treatment plants (STPs) in Seoul, South Korea in March 2011

Pharmaceuticals	TC (%)	JN (%)	NJ (%)	SN (%)
Acetylsalicylic Acid	99.9	99.9	99.6	99.9
Acetaminophen	99.8	99.8	98.0	99.5
Ibuprofen	99.3	99.4	99.1	97.5
Caffeine	98.2	99.4	95.7	96.9
Naproxen	91.7	95.5	95.5	94.3
Ciprofloxacin	81.1	89.0	74.0	82.8
Sulfamethoxazole	92.7	89.1	75.5	64.7
Chlorampenicol	93.5	94.3	34.4	92.3
Fenbendazole	91.6	46.6	ND	ND
Enrofloxacin	49.8	76.4	ND	56.9
Lincomycin	52.8	97.0	10.4	74.6
Florfenicol	82.8	8.7	ND	78.9
Oxitetracyclin	51.8	ND	49.1	54.6
Atenolol	57.8	78.4	-24.6	70.7
Trimethoprim	51.1	52.2	33.8	34.2
Diclofenac	22.1	35.3	-20.6	43.4
Sulfamethazine	ND	ND	-12.8	45.0
Mefenamic Acid	47.4	38.6	-44.0	-2.5
Roxithromycin	-24.8	-17.8	-66.5	10.5
Sulfathiazole	ND	ND	-56.3	ND
Erythromycin	ND	-37.8	ND	-76.1
Chlorotetracyclin	ND	ND	ND	ND
Tylosin	ND	ND	ND	ND

Note: TC = TanCheon, JR = JungRang, NJ = NanJi, SN = SeoNam

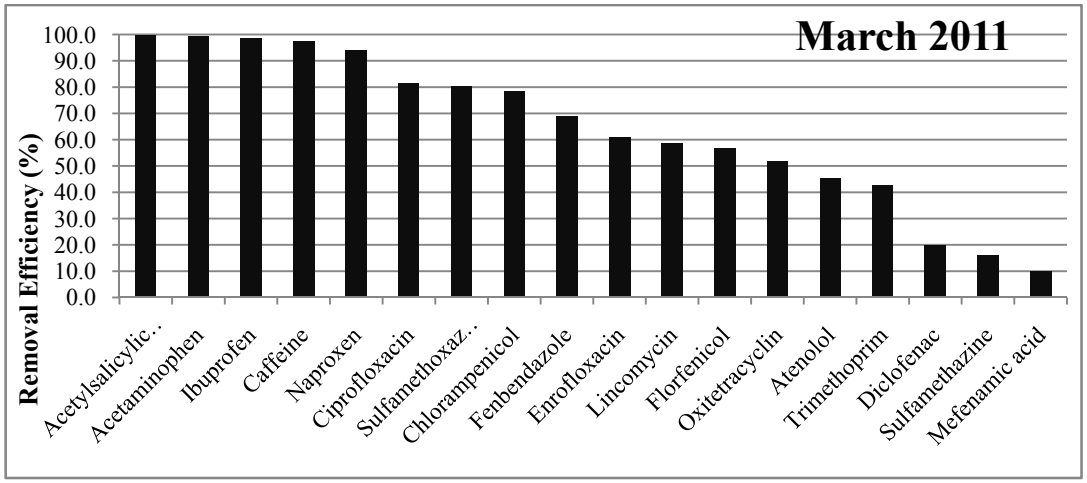

Fig. 4.11 Average removal of pharmaceuticals in four sewage treatment plants (STPs) in Seoul in March 2011

Florfenicol and lincomycin displayed large variation in their removal in the four STPs with a range between 8.7 - 82.85 and 52 - 92.7 %, respectively. Only about 50 % of oxytetracycline could be removed in the STPs during March 2011. However, florfenicol, oxytetracycline were not detected in both the influents and the effluents samples in the previous study conducted in May 2009 (Li, 2010).

Roxithromycin, sulfathiazole and erythromycin were not removed from almost all of the STPs. Atenolol, trimethoprim, diclofenac, mefenamic acid and sulfamethazine had low to moderate removal (ranging between 22.1% and 78.4%) and showed higher than influent concentrations in the effluents of some STPs. In the previous study conducted in May 2009 (Li, 2010), the concentrations of sulfathiazole, erythromycin, diclofenac, and sulfamethazine in the effluents were also found to be at higher levels as compared to influents. A similar trend was also observed in some recent studies (Bendz, et al., 2005, Nakada, et al., 2006, Gobel, et al., 2007, Hordern, et al. 2008, and Jelic´, et al., 2012). The reason for this has been explained in section 4.2.1.

4.7 Concentrations of the Pharmaceuticals' Residues in Han River

The concentrations of the pharmaceuticals' residues in the downstream receiving water body - Han River at four different locations are summarized in Table 4.17 and Fig. 4.12.

As shown in Table 4.17, the concentrations of the detected pharmaceuticals' residues in the Han River, at four different locations, were ranging between 0.2 ng/L and 2330 ng/L. Naproxen (ranging between 15.1 ng/Land 1,340 ng/L, average: 892.1ng/L), ibuprofen (ranging between 26.9ng/L to 2,330ng/L, average: 623.2ng/L), acetylsalicylic acid (ranging between: 32.4 ng/L and 1040 ng/L, average: 298.8ng/L) and caffeine (ranging between: 38.9 ng/L and 522 ng/L, average: 183.5ng/L) were detected to be at the top four levels in the river samples.

Table 4.17 Concentrations of pharmaceuticals' residues in Han River, Seoul, South Korea in March 2011

Points	AAP	ASA	CAF	IBP	MFN	NPX	DCF	ATEN
JSB	ND	32.4	38.9	26.9	21	15.1	9.22	ND
HNB	ND	81.4	83.5	75.9	171	2140	24.9	4.45
MPB	ND	41.4	89.7	60.1	84.2	73.3	17.8	2.48
BHB	2.64	1040	522	2330	394	1340	86.4	75.5
Points	**LCM**	**OTC**	**RTM**	**CAP**	**FFN**	**SMZ**	**SMX**	**TMP**
JSB	ND	ND	2.37	ND	1.43	1.62	1.97	3.17
HNB	5.43	ND	28.6	1.03	5.4	1.11	9.34	19.4
MPB	2.39	7.42	14.7	ND	2.01	1.37	6.82	13.1
BHB	34.9	20.2	52.1	13.5	3.4	4.03	10.6	84

Points	ENRO	CPF	STZ	CTC	FBD	ETM	TYL
JSB	0.164	ND	ND	ND	ND	ND	ND
HNB	ND	2.24	ND	ND	ND	ND	ND
MPB	ND	1.24	ND	ND	ND	ND	ND
BHB	1.54	47.7	3.15	ND	ND	ND	ND

Note: Unit in ng/L, BHB = BangHwa Bridge, MPB = MaPo Bridge, JSB = JamSil Bridge, HNB = HanNam Bridge

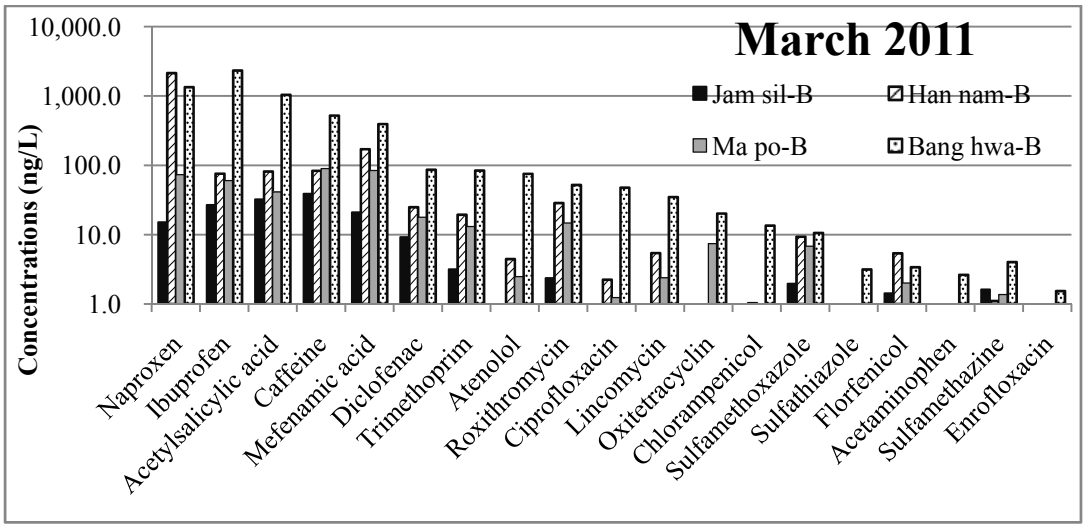

Fig. 4.17 Concentrations of pharmaceuticals' residues at four sampling locations in Han River in March 2011

Enrofloxacin, sulfamethazine acetaminophen, florfenicol sulfathiazole sulfamethoxazole and chloramphenicol were not frequently detected in the downstream waters. This is probably because of their efficient removal in the STPs, fast degradation in their ambient environment, or due to their relatively limited use in human medicine. This leads to their low influent concentrations in STPs, with the exception of sulfamethazine, florfenicol and sulfathiazole.

The concentrations of acetylsalicylic acid (1,040 ng/L) and caffeine (522 ng/L) at BangHwa Bridge and of florfenicol (5.4 ng/L) at HanNam Bridge, were detected to be higher as compared to the average levels of these pharmaceuticals in four STPs' effluents. This deserves attention, as normally we would expect the pharmaceuticals' levels in the surface water to be lower than those detected in the effluents. Acetylsalicylic acid and caffeine are both characterized by their rapid degradation (Sim et al., 2010) and hence; the concentrations of these compounds in the surface water were expected to be much lower than in the effluent. Therefore, this observation suggested that the STP's effluents may not be the major source of the presence of these pharmaceuticals in the surface water environment.

4.8 Comparison of Pharmaceuticals' Concentrations in Bangkok and Seoul

4.8.1 Removal Efficiencies of WWTPs / STPs

The comparison of removal efficiencies of WWTPs / STPs for detected pharmaceuticals in Bangkok and Seoul is shown in Fig.4.13.

It can be seen from Fig. 4.13 that the average removal efficiency of the four STPs in Seoul for acetylsalicylic acid was 99.8 %, followed by acetaminophen, (99.3 %), ibuprofen (98.8 %), caffeine (97.6 %), naproxen (94.3 %), ciprofloxacin (81.7 %) and lincomycin (75.6 %). The average removals of these pharmaceuticals in the five WWTPs in Bangkok were found to be relatively low except lincomycin (acetylsalicylic acid: 78.4 %, acetaminophen: 83.6 %, ibuprofen: 88 %, caffeine: 88.6

%, naproxen: 82 %, ciprofloxacin: 64.2 % and lincomycin: 92.15%). In general, the conventional activated sludge treatment process in STPs in Seoul could eliminate these pharmaceuticals very effectively. On the other hand, the conventional activated sludge treatment process in WWTPs in Bangkok was not as effective for removal of these pharmaceuticals. This could be due to the difference in operating parameters such as hydraulic retention time (HRT), solid retention time (SRT), redox conditions, and temperature, as well as physicochemical properties of wastewater that affect the removal of pharmaceuticals during conventional treatment.

The lowest average removal was found for mefenamic acid (9.9 %) in the four STPs in Seoul, followed by sulfamethazine (16.1 %), diclofenac (20.1 %) and trimethoprim (42.8 %). The average removals for these compounds were found to be comparatively higher in five WWTPs in Bangkok (mefenamic acid: 53.6 %, sulfamethazine: 26 %, diclofenac: 30.7% and trimethoprim: 74.8 %). It might be due to the different operating conditions of activated sludge treatment process used in the STPs in Seoul and WWTPs in Bangkok, as discussed above.

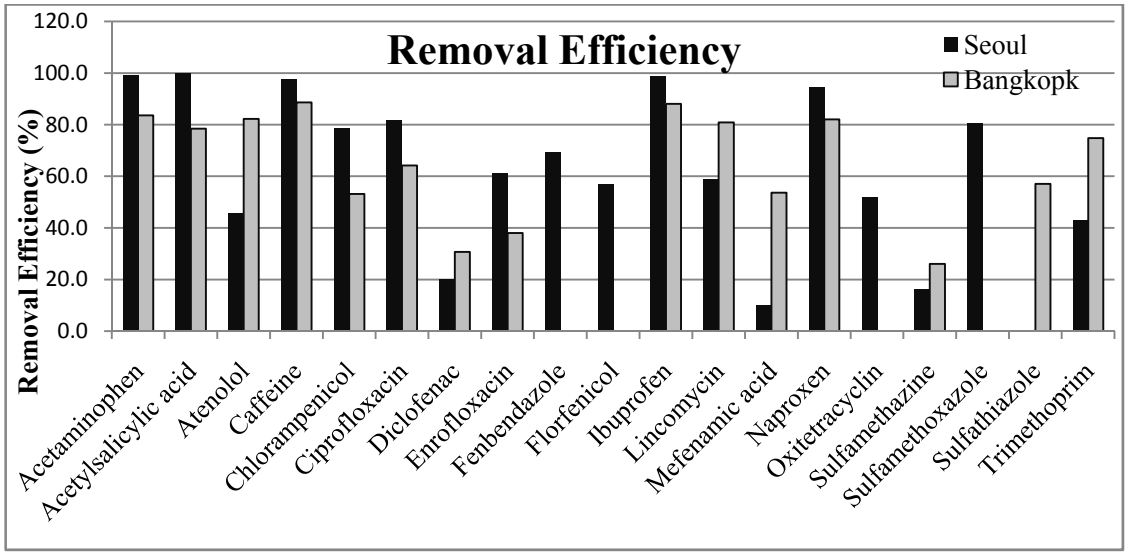

Fig. 4.13 Comparison of removal efficiencies of WWTPs in Bangkok and STPs in Seoul

Note: Florfenicol and oxitetracyclin were absent from all five WWTPs in Bangkok. Fenbendazole and sulfamethoxazole had higher effluent concentrations in WWTPs in Bangkok. Sulfathiazole also had higher effluent concentrations in STPs in Seoul.

4.8.2 Comparison of the Pharmaceuticals' Residues in the Chao Phraya River and the Han River

The comparison of the average concentrations of the pharmaceuticals' residues in the Han River in Seoul and the Chao Phraya River in Bangkok are shown in Fig.4.14.

It can be seen from Fig. 4.14, that, the highest average concentration of pharmaceutical residue in Han River, was found for naproxen (892.1ng/L), followed by ibuprofen (623.2 ng/L), acetylsalicylic acid (298.8 ng/L), caffeine (183.5 ng/L) and mefenamic acid (167.6 ng/L). On the other hand, the highest average residual concentration in Chao Phraya River were found to be for acetylsalicylic acid (312.6ng/L), followed by caffeine (122.6ng/L), acetaminophen (27.8 ng/L), ibuprofen (27.6 ng/L), and ciprofloxacin (23.9 ng/L). Naproxen (6.9 ng/L) was at the lowest level in Chao Phraya River while it was the highest concentration residual in the Han River. In general, the average levels of most of the 16 pharmaceuticals' residues detected in both rivers, were relatively higher in the Han River as compared to the Chao Phraya River (except for acetylsalicylic acid, acetaminophen and ciprofloxacin).

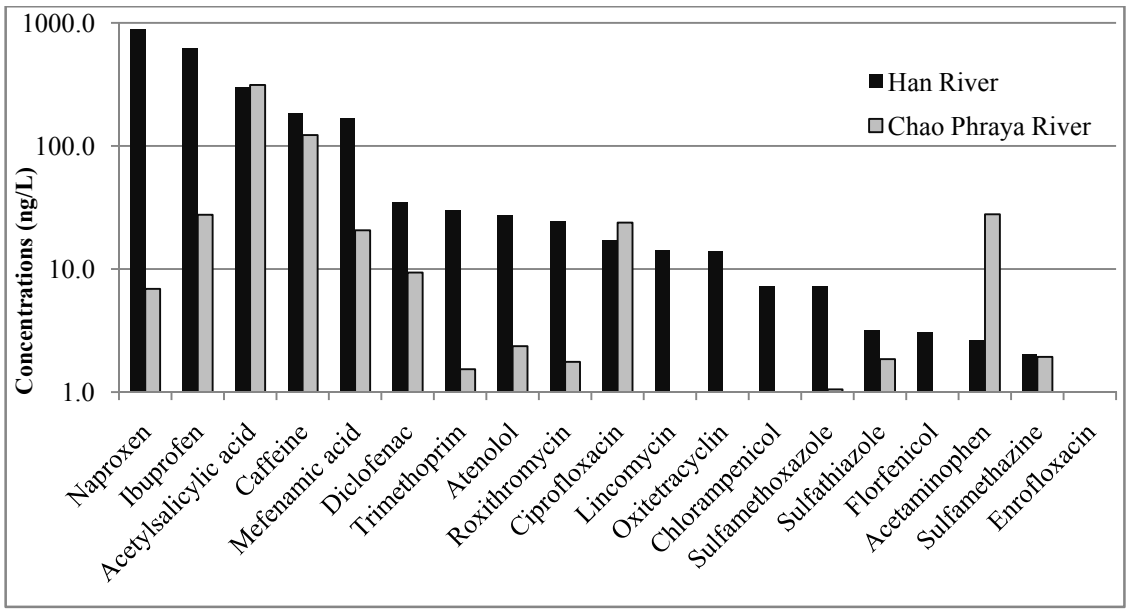

Fig. 4.14 Comparison of pharmaceuticals' residues in Chao Phraya River and Han River

Reasons for this could be 1) higher effluent concentrations from STPs in Seoul; and 2) lower flow conditions in Han River due to the dry season during the sampling event (March 2011).

4.9 Effect of Precipitation and the Population Served by the Treatment Plants on the Pharmaceuticals' Residues

4.9.1 Effect of Precipitation on the Pharmaceuticals' Residues

Rainfall data in the study area during the months of three sampling events and on the sampling dates is given in Table 4.18.

Table 4.18 Rainfall data over the study area during the months of three sampling events and on the sampling dates

Sampling event	Sampling date	Rainfall (mm/d)	Total rainfall during sampling dates (mm)	Total monthly rainfall (mm/month)
June 2011	3	32.6	124.5	412
	6	42.6		
	7	49.3		
September 2011	1	10.4	17.4	223.6
	2	3.8		
	5	0.8		
	6	2.0		
January 2012	4	4.5	4.5	44.2
	5	0.0		
	6	0.0		
	7	0.0		

Total rainfall over the Bangkok Metropolitan Area during the months of May 2011 and June 2011, were 98.1 mm and 226.4 mm higher, respectively than the normal rainfall for these months (based on historical data). Whereas, the total rainfall during the month of August 2011 was only 27.9 mm higher than the normal rainfall,

and in September 2011, it was 121.7 mm lower than the normal rainfall for this month. Thus, the flow conditions in the canals and river during June 2011 were assumed to be higher than in September 2011. Interestingly, while the precipitation in January 2012 was less than the other two sampling periods, the water levels and flows in the river and canals were very high because of the severe flooding in and around Bangkok region during September to December 2011 (Thai Meteorological Department, 2012). Hence, the flow conditions in the river and canals were assumed to be the highest during January 2012, and lowest during September 2011.

The overall average concentrations of the detected pharmaceuticals in the Chao Phraya River and six canals are presented in Table 4.19 and Fig 4.20.

Table 4.19 Overall average concentrations of pharmaceuticals' residues in Chao Phraya River and six canals during three flow conditions

	River	KBL	KPK	KSS	KBJ	KKH	KCN
June 2011 (Medium Flow)	46.7	126.5	199.0	87.1	85.5	169.3	901.0
September 2011 (Low Flow)	64.9	957.4	224.9	120.9	86.1	145.4	181.5
January 2012 (High Flow)	22.0	88.2	28.3	44.8	53.8	54.1	34.5

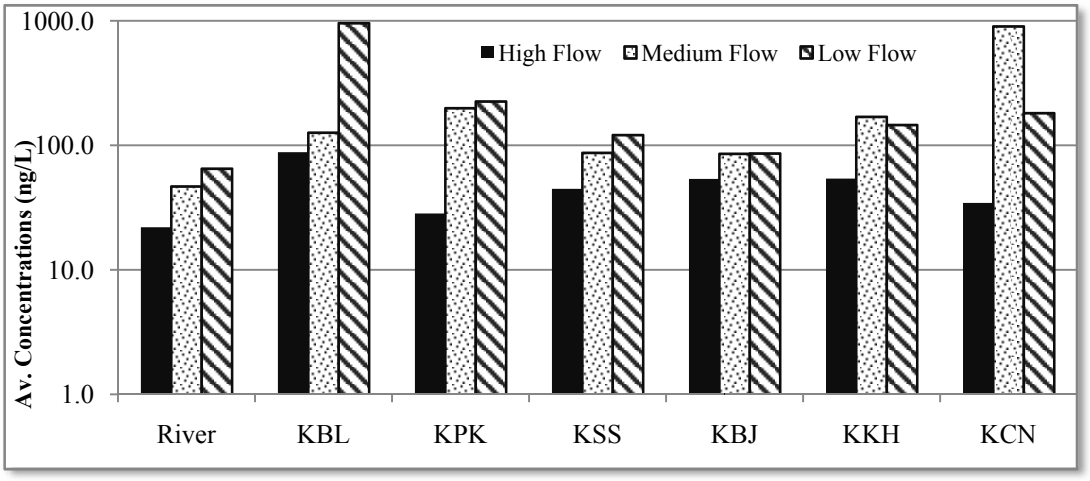

Fig. 4.20 Overall average pharmaceuticals' concentrations in Chao Phraya River and six canals during three flow conditions

Concentrations of detected pharmaceuticals' residues in the river and six canals during the low flow season, (September 2011), were ranging between 0.47 ng/L and 1,100 ng/L (Table 4.12), and 0.44 ng/L and 22,300 ng/L (Table 4.6), respectively. The overall average concentration of the fifteen detected pharmaceuticals' residues in Chao Phraya River during the low flow season was 69.9 ng/L. Overall average levels of the eighteen detected pharmaceuticals' residues in six canals during the same sampling event, ranged between 86.1 ng/L and 957.4 ng/L. Concentrations of 14 detected pharmaceuticals' residues in the river and six canals during the medium flow season, (June 2011), were ranging between 0.6 ng/L – 258 ng/L (Table 4.11), and 0.27 ng/l and 8,350 ng/L (Table 4.5), respectively. The overall average concentration of the eleven detected pharmaceuticals' residues in Chao Phraya River during the medium flow season was 46.7 ng/L. Overall average levels of the seventeen detected pharmaceuticals' residues in six canals during the same sampling event, ranged between 85.5 ng/L and 901.0 ng/L. Whereas, concentrations of the detected pharmaceuticals' residues in Chao Phraya River during the high flow season (January 2012) ranged between 0.29 ng/L and 179 ng/L (Table 4.13) and between 1.4 ng/L and 932.5 ng/L in the six canals (Table 4.7). As shown in Table 4.19 and Fig. 4.15, the overall average concentration of the fourteen detected pharmaceuticals' residues in Chao Phraya River during the high flow season was 22.2 ng/L. Overall average levels of the eighteen detected pharmaceuticals' residues in six canals during the same sampling event, ranged between 28.3 ng/L and 88.2 ng/L.

The average concentrations of the detected pharmaceuticals' residues in the river and canals during the low flow conditions were found to be at higher levels (1.6 time and 11 times, respectively), as compared to the high flow conditions. The reason for this difference could be due to the dilution of the pharmaceuticals' residues in canals and river during the high flow conditions. Canal KBL showed the maximum variations between the two seasons (11 times higher in the low flow conditions as compared to the high flow season). On the other hand, canal KBJ did not show much variation between the two seasons. Moreover, the average concentrations of the pharmaceuticals' residues in the canals – KKH and KCN, were found to be highest

during the medium flow condition as compared to the low flow condition. This can be explained by the seasonal rainfall pattern over the areas.

Based on the results of this study, it can be said that, in general, there were no significant differences in the individual concentrations of most of the pharmaceuticals' residues in the Chao Phraya River and in the canals during the low flow condition (September 2011) and the high flow condition (January 2012). However, the level of acetylsalicylic acid was found to be much higher in the low flow than those in the high flow in the river. Similarly, the levels of acetylsalicylic acid, caffeine, and mefenamic acid in the canals were also found to be at much higher levels during low flow period compared to the high flow. Ciprofloxacin was detected only once at 1-R7B during low flow condition in river. These observations clearly show that the flow condition influences the levels of pharmaceutical residues in receiving water bodies.

4.9.2 Effect of Population on the Levels of the Pharmaceuticals in the WWTPs

The RK and SP WWTPs mostly cover the tourist and commercial areas of Bangkok (especially RK) where the amount and quality of wastewater entering the plant can be significantly affected by the seasonal population growth. On the other hand, CN, DD, and TK WWTPs mostly cover the local residential, commercial and offices areas, where the amount and the quality of water entering the plant are much affected by the seasonal conditions due to changing weather patterns. To estimate the effect of population, it was assumed that pharmaceuticals' consumption patterns of the permanent local residents (inhabitants) as well as transient population were the same.

Average daily loads of the detected pharmaceuticals in influents of five WWTPs during three sampling events (expressed as mg/d/1000 inhabitants) are shown in Table 4.20. Total daily loads (sum of the loads of all detected pharmaceuticals) in influents of five WWTPs during three sampling events (expressed as mg/d/1000 inhabitants), are shown in Table 4.21 and Fig. 4.16.

As shown in Table 4.21, the total daily influent loads (sum of the loads of 18 detected pharmaceuticals) in RK during three sampling events, for 1000 inhabitants, was in general relatively higher than those in the other 4 plants. However, during June 2011 sampling event, the daily average influent loads of the detected pharmaceuticals in CN WWTP was highest (7.27 mg/d/1000 inhabitants), followed by RK WWTP (5.54 mg/d/1000 inhabitants).

Table 4.20 The Average daily loads of the detected pharmaceuticals in influents of five WWTPs during three sampling events (expressed as mg/d/1000 inhabitants)

	SP	RK	TK	CN	DD
AAP	0.26	0.38	0.06	0.28	0.08
ASA	1.60	3.92	0.17	2.35	0.77
ATEN	0.06	0.10	0.04	0.06	0.06
CAF	0.79	1.24	0.36	0.72	0.86
CAP	0.00	0.00	0.00	0.00	0.00
CPF	0.04	0.08	0.05	0.08	0.07
DCF	0.04	0.06	0.03	0.05	0.07
ENRO	0.00	0.00	0.00	0.00	0.00
FBD	0.00	0.00	0.00	0.00	0.00
IBP	0.14	0.34	0.19	0.29	0.31
LCM	0.00	0.00	0.00	0.01	0.00
MFN	0.17	0.29	0.14	0.26	0.26
NPX	0.06	0.09	0.03	0.14	0.08
RTM	0.00	0.00	0.00	0.00	0.00
SMX	0.00	0.00	0.00	0.00	0.00
SMZ	0.01	0.01	0.01	0.02	0.01
STZ	0.05	0.06	0.02	0.04	0.05
TMP	0.01	0.02	0.01	0.04	0.02

Note: the loads were normalized by the population equivalent of each plant

Table 4.21 Total daily loads of all the detected pharmaceuticals in influents of five WWTPs during three sampling events, (expressed as mg/d/1000 inhabitants)

Sampling Events	SP	RK	TK	CN	DD
June 2011	2.8	5.5	1.5	7.3	3.6
September 2011	5.6	10.4	0.9	3.5	2.6
January 2012	1.3	3.8	0.9	2.2	1.8

Overall average loads of all the detected pharmaceuticals in RK and SP during the three sampling events, were 6.59 mg/d/1000 inhabitants (ranging between .001 and 3.92 mg/day/1000 inhabitants) and 3.23 mg/d/1000 inhabitants (ranging between 0.001- 1.60 mg/d/1000 inhabitants), respectively. Overall average loads of all the detected pharmaceuticals in CN, DD and TK during the three sampling events, were 4.33 mg/d/1000 inhabitants (ranging between 0.001 - 2.35 mg/d/1000 inhabitants), 2.65 mg/d/1000 inhabitants (ranging between 0.001 – 0.86 mg/d/1000) and 1.11 mg/d/1000 inhabitants (ranging between 0.001 – 0.36 mg/d/1000), respectively.

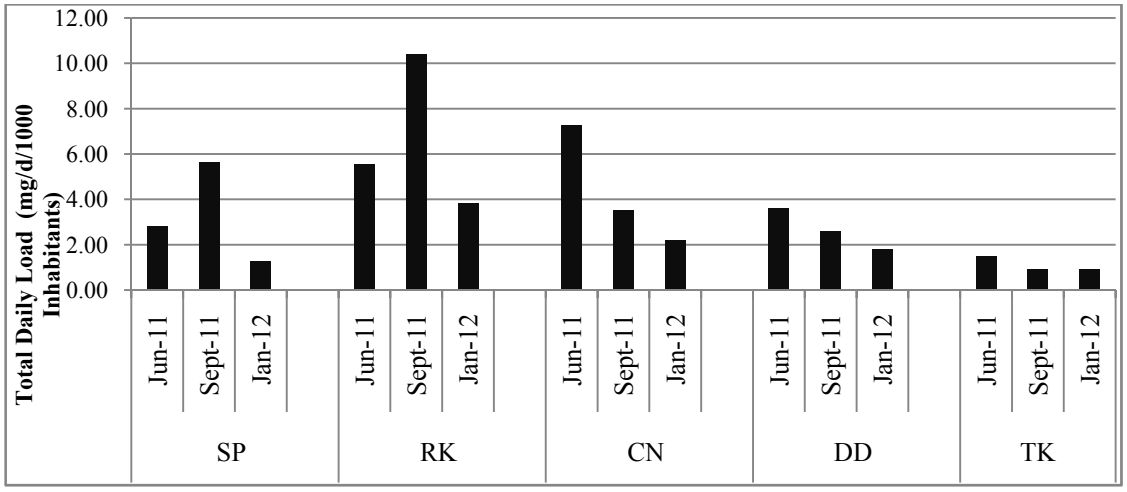

Fig. 4.21 Total daily loads of the detected pharmaceuticals in influents of all five WWTPs, during three sampling events, for 1000 inhabitants

As shown in Fig. 4.21, the total influent loads of the detected pharmaceuticals, in SP and RK WWTPs varies with tourist seasons, such as highest total daily influent loads were found during September 2011 in both WWTPs (probably due to the pleasant weather conditions as compared to June 2011 and January 2012,). The lowest total influent loads were found in January 2012, when there were comparatively less tourists in Bangkok, due to the severe flooding during October - December 2011. The total daily loads of the detected pharmaceuticals were found to be 4.42 times higher in SP and 2.71 times higher in RK WWTPs during September 2011 as compared to January 2012. Whereas, the total influent loads of the detected pharmaceuticals, in CN, DD and TK WWTPs varied with weather conditions,

e.g., higher daily loads were found during the summer season (June 2011) as compared to winter season (January 2012). This could be due to higher pharmaceuticals consumption, because of increased occurrences of illnesses caused by frequent change in weather. The total influent loads of the detected pharmaceuticals during June 2011, were 3.31 times higher in CN, 2.03 times higher in DD and 1.64 times higher in TK WWTPs as compared to January 2012.

4.10 Ecological Risk Calculations of the Pharmaceuticals' Residues on the Environment

Effluents from the all wastewater treatment plants in Bangkok are discharged into receiving water environments, which may lead to negative impact on the aquatic ecosystems. The risk associated with residual pharmaceuticals transmitted from effluents or other sources to receiving water bodies is usually characterized as the ratio of environmental concentrations (predicted or measured concentrations) to predicted no-effect concentrations (PNECs) known as hazard quotient (HQ). Although, it is very difficult to estimate the environmental levels of any pharmaceuticals, at which adverse effects on aquatic organisms may occur, the hazard quotient (HQ) could be a useful measure that can be employed to characterize potential ecological risk of a stressor, in this case pharmaceuticals (Kim et al., 2007).

The HQs for all tested pharmaceuticals were derived based on the measured concentrations of the pharmaceuticals (MEC) including maximum and 95% UCL in the effluents and surface waters, like Chao Phraya River and six canals. To reflect more conservative exposure scenario, maximum occurrence data were used for MEC calculation. PNECs were obtained from the literature (Choi et al., 2008b; Jones et al., 2002; National Institute of Environmental Research, 2010; Souza et al. 2009; www.fass.se; Yamamoto et al., 2007).

4.10.1 Hazard Quotients (HQs) of the Pharmaceuticals' Residues in the Receiving Waters during June 2011 Sampling Event

Hazard quotients (HQs) were obtained to evaluate the ecological impact on aquatic organisms due to the presence of pharmaceuticals' residues in WWTPs effluents, canals and Chao Phraya River, in Bangkok, Thailand, during June 2011. The calculated HQs for maximum and 95% UCL concentrations in the effluents, six canals and Chao Phraya River are summarized in Table 4.22. Measured environmental concentrations used for HQs calculation are summarized in Table A.1 in Appendix A.

Table 4.22 Hazard quotients of the detected pharmaceuticals in WWTPs, six canals and Chao Phraya River in Bangkok, Thailand during June 2011 sampling event

Pharma-ceutical	PNEC (μg/L)	Effluents	Effluents	canals	canals	River	River
		Max	$UCL_{95\,\%}$	Max	$UCL_{95\,\%}$	Max	$UCL_{95\,\%}$
AAP	6.2[1]	0.1	0.1	0.2	0.1	0.0	0.0
ASA	10[1]	0.1	0.0	**0.8**	0.3	0.0	0.0
ATEN	100[2]	0.0	0.0	0.0	0.0	0.0	0.0
CAF	182[1]	0.0	0.0	0.0	0.0	0.0	0.0
CAP	0.64[1]	0.0	0.0	0.0	0.0	0.0	0.0
CPF	0.05[1]	**4.6**	**3.6**	**3.9**	**2.0**	0.0	0.0
DCF	0.1[1]	**1.8**	**1.5**	**1.2**	**1.0**	0.1	0.1
ENRO	0.98[1]	0.0	0.0	0.0	0.0	0.0	0.0
FBD	16.5[1]	0.0	0.0	0.0	0.0	0.0	0.0
IBP	9.06[1]	0.0	0.0	0.1	0.0	0.0	0.0
LCM	7[1]	0.0	0.0	0.0	0.0	0.0	0.0
MFN	0.43[3]	**1.1**	**1.0**	**1.6**	**1.1**	0.1	0.1
NPX	0.64[4]	0.0	0.0	0.0	0.0	0.0	0.0
RTM	7.1[1]	0.0	0.0	0.0	0.0	0.0	0.0
SMZ	0.15[5]	0.0	0.0	0.0	0.0	0.0	0.0
SMX	5[1]	**0.6**	0.4	0.4	0.2	0.0	0.0
STZ	44.4[1]	0.0	0.0	0.0	0.0	0.0	0.0
TMP	0.1[6]	0.2	0.2	**0.6**	0.3	0.0	0.0

Note: PNEC = predicted no effect concentration, Max = maximum, 95%UCL = 95% of upper confidence limit of the mean, PNEC values are from – [1] National Institute of Environmental Research 2010; [2] Yamamoto et al. 2007; [3] Jones et al. 2002; [4] www.fass.se; [5] Choi et al. 2008b; [6] Souza et al. 2009

As shown in Table 4.22 the HQs for all detected pharmaceuticals in Chao Phraya River appeared to be much less than one (below 0.1). These results suggest that the potential environmental impact of pharmaceuticals in Chao Phraya River may be very low. However, HQs calculated for effluents and canals were relatively higher. The HQs for ciprofloxacin in effluents and canals were almost 4 - 5 times higher than the PNECs, suggesting that there may be a very high risk of this pharmaceutical to the aquatic organisms. HQs for diclofenac and mefenamic acid in most of the effluents and canals were greater than 1, suggesting potential risks to the aquatic organisms. The HQ values for acetylsalicylic acid, sulfamethoxazole and trimethoprim, based on maximum concentrations in WWTPs and canals were more than 0.5, suggesting the moderate potential risks to the aquatic organisms.

4.10.2 Hazard Quotients (HQs) of the Pharmaceuticals' Residues in the Receiving Waters during September 2011 Sampling Event

Hazard quotients (HQs) of pharmaceuticals' residues in WWTPs effluents, canals and Chao Phraya River, in Bangkok, Thailand, during September 2011were obtained for maximum and 95% UCL concentrations as shown in Table 4.23. Measured environmental concentrations used for HQs calculation are summarized in Table A.2 in Appendix A.

As shown in Table 4.23, the HQs for all detected pharmaceuticals in Chao Phraya River appeared to be much less than one (below 0.1) except for ciprofloxacin that showed the HQ value of 1 for maximum and 0.8 for 95% UCL concentrations. These results suggest that the potential environmental impact of most of the detected pharmaceuticals in Chao Phraya River may be low, but there is a need to do further investigations in the future. However, HQs calculated for some pharmaceuticals' residues in effluents and canals were relatively higher than in river. The HQs for ciprofloxacin in effluents and canals were more than 1, suggesting that there may be a very high risk of this pharmaceutical to the aquatic organisms. HQs for acetylsalicylic acid in canals, and for diclofenac and mefenamic acid in most of the effluents and canals were either greater than or approaching one, thus also suggesting potential risks of these to aquatic organisms. The HQ values for trimethoprim in canals, based on

maximum concentrations were more than 0.5, suggesting the moderate potential risks to the aquatic organisms.

Table 4.23 Hazard quotients of the detected pharmaceuticals in WWTPs, six canals and Chao Phraya River in Bangkok, Thailand during September 2011 sampling events

Pharma-ceutical	PNEC (µg/L)	Effluents	Effluents	canals	canals	River	River
		Max	UCL 95 %	Max	UCL 95 %	Max	UCL 95 %
AAP	6.2[1]	0.0	0.0	0.1	0.0	0.0	0.0
ASA	10[1]	0.1	0.0	**2.2**	**0.7**	0.1	0.1
ATEN	100[2]	0.0	0.0	0.0	0.0	0.0	0.0
CAF	182[1]	0.0	0.0	0.0	0.0	0.0	0.0
CAP	0.64[1]	0.0	0.0	0.0	0.0	0.0	0.0
CPF	0.05[1]	**1.5**	**1.2**	**3.9**	**1.7**	**1.0**	**0.8**
DCF	0.1[1]	**0.9**	**0.9**	**2.1**	**1.1**	0.1	0.1
ENRO	0.98[1]	0.0	0.0	0.0	0.0	0.0	0.0
FBD	16.5[1]	0.0	0.0	0.0	0.0	0.0	0.0
IBP	9.06[1]	0.0	0.0	0.1	0.0	0.0	0.0
LCM	7[1]	0.0	0.0	0.0	0.0	0.0	0.0
MFN	0.43[3]	**0.7**	**0.7**	**2.0**	**1.1**	0.0	0.0
NPX	0.64[4]	0.0	0.0	0.1	0.0	0.0	0.0
RTM	7.1[1]	0.0	0.0	0.0	0.0	0.0	0.0
SMZ	0.15[5]	0.0	0.0	0.0	0.0	0.0	0.0
SMX	5[1]	0.1	0.1	0.1	0.1	0.0	0.0
STZ	44.4[1]	0.0	0.0	0.0	0.0	0.0	0.0
TMP	0.1[6]	0.2	0.1	**0.8**	0.3	0.0	0.0

Note: PNEC = predicted no effect concentration, Max = maximum, 95%UCL = 95% of upper confidence limit of the mean, PNEC values are from – [1] National Institute of Environmental Research 2010; [2] Yamamoto et al. 2007; [3] Jones et al. 2002; [4] www.fass.se; [5] Choi et al. 2008b; [6] Souza et al. 2009

4.10.3 Hazard Quotients (HQs) of the Pharmaceuticals' Residues in the Receiving Waters during January 2012 Sampling Event

Hazard quotients (HQs) of pharmaceuticals' residues in WWTPs effluents, canals and Chao Phraya River, in Bangkok, Thailand, during January 2012 were obtained for maximum and 95% UCL concentrations as shown in Table 4.24. Measured environmental concentrations used for HQs calculation are summarized in Table A.3 in Appendix A.

Table 4.24 Hazard quotients of the detected pharmaceuticals in WWTPs, six canals and Chao Phraya River in Bangkok, Thailand during January 2012 sampling events

Pharma-ceutical	PNEC (μg/L)	Effluents	Effluents	canals	canals	River	River
		Max	UCL $_{95\,\%}$	Max	UCL $_{95\,\%}$	Max	UCL $_{95\,\%}$
AAP	6.2[1]	0.0	0.0	0.0	0.0	0.0	0.0
ASA	10[1]	0.0	0.0	0.0	0.0	0.0	0.0
ATEN	100[2]	0.0	0.0	0.0	0.0	0.0	0.0
CAF	182[1]	0.0	0.0	0.0	0.0	0.0	0.0
CAP	0.64[1]	**1.4**	**1.4**	**1.5**	**0.9**	0.0	0.0
CPF	0.05[1]	**1.8**	**1.5**	**1.2**	**0.8**	0.2	0.2
DCF	0.1[1]	0.0	0.0	0.0	0.0	0.0	0.0
ENRO	0.98[1]	0.0	0.0	0.0	0.0	0.0	0.0
FBD	16.5[1]	0.0	0.0	0.1	0.0	0.0	0.0
IBP	9.06[1]	0.0	0.0	0.0	0.0	0.0	0.0
LCM	7[1]	**0.6**	**0.6**	**0.6**	0.4	0.1	0.1
MFN	0.43[3]	0.0	0.0	0.0	0.0	0.0	0.0
NPX	0.64[4]	0.0	0.0	0.0	0.0	0.0	0.0
RTM	7.1[1]	0.0	0.0	0.0	0.0	0.0	0.0
SMZ	0.15[5]	0.2	0.1	0.1	0.1	0.0	0.0
SMX	5[1]	0.0	0.0	0.0	0.0	0.0	0.0
STZ	44.4[1]	0.2	0.2	0.3	0.2	0.0	0.0
TMP	0.1[6]	0.0	0.0	0.0	0.0	0.0	0.0

Note: PNEC = predicted no effect concentration, Max = maximum, 95%UCL = 95% of upper confidence limit of the mean, PNEC values are from – [1] National Institute of Environmental Research 2010; [2] Yamamoto et al. 2007; [3] Jones et al. 2002; [4] www.fass.se; [5] Choi et al. 2008b; [6] Souza et al. 2009

As shown in Table 4.24, the HQs for all detected pharmaceuticals in Chao Phraya River appeared to be much less than one (below 0.2), suggesting that the potential environmental impact of these on aquatic organisms in river may be low. However, HQs calculated for some pharmaceuticals' residues in effluents and canals were relatively higher than in river. Similar to June 2011 and September 2011, the HQs for ciprofloxacin and diclofenac in the effluents and canals were either greater than or approaching one, suggesting high potential risks to aquatic organisms. The HQ values for mefenamic acid in most of the WWTPs and canals were more than 0.5, suggesting the moderate potential risks to the aquatic organisms. Mixture effects of

these pharmaceuticals and their degradation products in effluent and canals should also be considered in the future risk assessment.

Results of the three sampling events indicated low/no ecological impact of most of the pharmaceuticals' residues in Chao Phraya River on aquatic organisms, except for ciprofloxacin, which showed the high risk in September 2011 sampling event. HQs for acetylsalicylic acid, ciprofloxacin, diclofenac and mefenamic acid in most of the effluents and canals were either greater than or approaching one, suggesting very high potential risks to aquatic organisms. The HQ values for sulfamethoxazole and trimethoprim in WWTPs and canals were more than 0.5, suggesting moderate potential risks to the aquatic organisms.

The pharmaceuticals that were estimated to have high ecological impact in this study, have also been reported to have potential risks to the aquatic organisms in surface waters of other regions around the world. Potential high risks for acetylsalicylic acid, diclofenac, ibuprofen, naproxen, and acetaminophen were estimated in surface water of Spain and Denmark (Hernando et al., 2000; Stuer-Lauridsen et al., 2000). In China, HQ value for salicylic acid, ibuprofen and diclofenac were reported to be of medium to high risk to the aquatic organisms in several rivers (Wong et al., 2009; Zhao et al., 2010). The maximum occurrence levels of some pharmaceuticals: acetaminophen, ciprofloxacin, diclofenac, ibuprofen and trimethoprim were reported to be of high risk in the Taiwanese waters (Lin et al., 2008). Ying et al. (2009) reported high HQ value of diclofenac in Australian sewage effluents.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Present study was aimed at detecting and comparing the occurrence and fate of some selected pharmaceuticals in five wastewater treatment plants (WWTPs) and receiving water bodies (six canals and Chao Phraya River) in Bangkok, Thailand, as well as in four sewage treatment plants (STPs) and the Han River in Seoul, South Korea. Samples were collected from influents, mid-process, effluents of the WWTPs / STPs, and receiving waters (canals and river) during the four sampling events - March 2011 in Seoul, and June 2011, September 2011, and January 2012 in Bangkok. All the samples were analyzed by high performance liquid chromatography – mass spectrometry – mass spectrometry (HPLC/MS/MS) following the solid phase extraction (SPE). The twenty three pharmaceuticals analyzed included: acetaminophen, acetylsalicylic acid, atenolol, caffeine, ciprofloxacin, diclofenac, ibuprofen, mefenamic acid, naproxen, roxithromycin, sulfamethazine, sulfamethoxazole, sulfathiazole and trimethoprim.

Result showed that levels of the detected pharmaceutical residues in the influents, were highest for acetylsalicylic acid (average: 4,699.4 ng/L), followed by caffeine (2,250.5 ng/L) and ibuprofen (701.9 ng/L) in Bangkok, and acetylsalicylic acid (70,175 ng/L), ibuprofen (4,667.5 ng/L) and naproxen (2,905 ng/L) in Seoul. In Bangkok and Seoul, in mid-process: acetylsalicylic acid (216 and 2,420 ng/L, respectively), mefenamic acid (203 ng/L and 1,186.3 ng/L, respectively) and caffeine (9.6 ng/L and 255.5 ng/L, respectively). However, the top three effluent concentrations were found to be for caffeine (307.1 ng/L), acetylsalicylic acid (260.5 ng/L) and mefenamic acid (251.4 ng/L) in Bangkok, and mefenamic acid (488.3 ng/L), naproxen (161.8 ng/L) and roxithromycin (152.3 ng/L). In canals, most of the pharmaceuticals were detected at relatively higher levels upstream of WWTPs as

compared to downstream regions. Among each of the six canals, the highest concentrations were found for acetylsalicylic acid in canal KRK (3907.1 ng/L), followed by caffeine (1541 ng/L in canal KCN). It is noteworthy, that on an average, these two canals had most of the pharmaceuticals at higher levels as compared to other four canals. Similar to the canals, the highest levels in river water samples in Bangkok during three sampling events, were also found for acetylsalicylic acid (on average: 312.6 ng/L), followed by caffeine (122.6 ng/L). Naproxen (892.1 ng/L), ibuprofen (6223.2 ng/L) and acetylsalicylic acid (298.8 ng/L) were found highest levels in Han River in Seoul. Most of the samples from canal water and some from the river water generally had relatively higher levels of pharmaceuticals compared to the effluents of the WWTPs. Thus it was evident that, not only the WWTPs but other sources were responsible for release of these compounds into receiving waters.

Good removals (on average: > 80%) were observed for acetaminophen, atenolol, caffeine, ibuprofen and naproxen in all WWTPs in Bangkok. Acetylsalicylic acid, ciprofloxacin, sulfathiazole and trimethoprim had moderate removals (average: 55-80%). In Seoul, high removals (on average: > 80 %) were found for acetaminophen, acetylsalicylic acid, caffeine, ciprofloxacin, naproxen and Sulfamethoxazole. Chlorampenicol, enrofloxacin, fenbendazole, florfenicol and lincomycin had moderate removals (average: 55-80%). While, roxithromycin, sulfamethoxazole and sulfamethazine were not removed in most of the WWTPs / STPs in Bangkok and Seoul. HRT appeared to play a role on removal for 8-9 pharmaceuticals, which had higher elimination rates with increasing HRT (9 out of 14 pharmaceuticals were removed above 80 % at 11 h HRT in CN WWTP). At low HRT (6 - 6.5 h), caffeine and some NSAIDs showed fast degradation rate (low $t_{1/2}$). While roxithromycin, sulfamethoxazole and sulfamethazine were not removed (very high $t_{1/2}$) in most of the WWTPs, irrespective of the HRT.

Among three seasonal conditions, acetylsalicylic acid was found to be at much higher levels in the Chao Phraya River during the low flow condition (September 2011) than those during the high flow (January 2012). Ciprofloxacin was detected only once at 1-R7B, during low flow condition in river. In canals -

acetylsalicylic acid, caffeine, and mefenamic acid were found at much higher levels in the low flow condition compared to the high flow condition. Concentrations of detected pharmaceuticals residues in the river and canals, during the low flow condition, were higher (almost 3 times and 1.6-10.9 times, respectively) as compared to high flow condition.

The RK and SP WWTPs are situated in the tourist and commercial areas of Bangkok, where the amount and quality of wastewater entering the plant can be significantly affected by the seasonal population growth. Highest daily loads of detected pharmaceuticals in the influents of these two WWTPs were found during the tourist season (September 2011). On the other hand, CN, DD, and TK WWTPs are situated around the local residential, commercial and offices areas, where the amount and the quality of wastewater entering the plants are very much affected by the seasonal conditions due to changing weather patterns. Highest daily loads were found during summer season (June 2011). This could be due to higher pharmaceuticals consumption, because of increased occurrences of illnesses caused by frequent change in weather.

The HQs calculated for majority of the test pharmaceuticals in canals and river were less than one, suggesting that their potential for ecological impact may be low. However, acetylsalicylic acid, ciprofloxacin, diclofenac and mefenamic acid showed HQ values greater than one. Further evaluation of potential environmental risks of pharmaceuticals is required.

Some of the limitations encountered in this study included: 1) due to the cost factor of expensive analyses for pharmaceuticals detection, only one sample was taken from each sampling point for analysis, 2) in case of Seoul, South Korea, due to the limited time duration of summer internship period, only one sampling could be carried out, and 3) sampling from all four STPs in Seoul, South Korea were done by different people.

The results of this study could be helpful in identifying the knowledge gaps and research needs on the following:

1) fate and occurrence of pharmaceuticals' residues in effluents of WWTPs, receiving surface waters in Bangkok, Thailand

2) factors influencing the removal of pharmaceuticals in WWTPs, and

3) potential ecological risks of pharmaceuticals' residues on aquatic organisms in water resources in Bangkok, Thailand.

The outcome of such a study may contribute to the development of National Plan for the management of the pharmaceuticals residues in WW effluents and surface water that are the byproducts of manufacturing of various types of such products in extensive use at present.

5.2 Recommendations

Further study is necessary to have a real picture of the fate of pharmaceuticals in aquatic environments. Due to the cost factor of expensive analyses for pharmaceuticals detection, the number of samples in this study was reduced. However, it is recommended to have the better experimental design with more number of samples to enhance the reliability of the results.

More research should be carried out to evaluate the influence of the different treatment processes employed in the treatment plants on the removal efficiencies for pharmaceuticals (e.g. membrane bioreactors, wetland, ozonation). The results of many past studies show the very good removal of the pharmaceuticals could be achieved as compared to convectional activated sludge treatment process.

More research work is needed to learn about the fate of PPCPs during the WWTP treatment processes based on the mass balance in order to understand the removal of pharmaceuticals.

High HQ values for some pharmaceuticals' residues in receiving waters indicated the potential risks on the aquatic environments. Ecological implications of the pharmaceuticals' residues in Bangkok waterway warrant further investigations.

There is a critical need for targeted ecotoxicological studies focusing on chronic subtle but ecologically meaningful environmental effects of pharmaceuticals and their metabolites, individually or in mixture, to fully understand potential impacts on the aquatic environments of those drugs that showed HQ values to be more than or approaching one (Fent et al., 2006). Prioritizing future research efforts based on potential ecological risks is also important considering number of pharmaceuticals in use and limited socioeconomic resources (Ankley et al., 2007; Kostich and Lazorchak, 2008, Choi et al., 2008).

Future research work is also needed to be carried out for investigating pharmaceuticals' residues in effluents from hospital's WWTPs, ground water and drinking water treatment plants.

Until now, there are no standards for pharmaceuticals' residues in WWTPs' effluents, surface water and drinking water in any country around the world. Hence, there is a critical need for some guidelines and regulations for emerging micropollutants such as pharmaceuticals' residues in water environments worldwide including Thailand.

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APPENDIX

Measured environmental concentrations (MEC) used for HQs calculation

Table A.1 MEC values used for HQs calculation, during June 2011 sampling event

Pharmaceuticals	Effluents	Effluents	Canals	Canals	River	River
	Max	UCL 95 %	Max	UCL 95 %	Max	UCL 95 %
Acetaminophen	734.0	512.2	1,150.0	610.3	134.0	128.4
Acetylsalicylic A.	546.0	492.1	8,350.0	2,717.0	199.0	182.0
Atenolol	62.5	54.1	112.0	56.7	4.5	4.5
Caffeine	1,720.0	1,147.4	2,740.0	1,264.7	258.0	284.9
Chlorampenicol	1.1	1.1	1.1	0.6	-	-
Ciprofloxacin	231.0	178.9	196.0	101.2	-	-
Diclofenac	182.0	150.1	122.0	95.2	11.5	11.7
Enrofloxacin	-	-	-	-	-	-
Fenbendazole	-	-	1.6	0.7	-	-
Ibuprofen	149.0	135.7	622.0	312.0	49.4	50.9
Lincomycin	0.8	0.8	8.8	3.2	-	-
Mefenamic acid	461.0	446.0	688.0	479.3	40.4	42.8
Naproxen	159.0	120.5	108.0	87.4	41.3	36.0
Roxithromycin	5.8	5.0	9.9	4.5	0.9	1.0
Sulfamethoxazole	88.9	60.4	58.5	26.4	1.9	2.3
Sulfamethazine	128.0	94.9	85.7	44.4	-	-
Sulfathiazole	159.0	142.1	89.1	69.3	-	-
Trimethoprim	23.8	20.3	64.6	29.5	1.7	1.7

Table A.2 MEC values used for HQs calculation, during September 2011 sampling event

Pharmaceuticals	Effluents	Effluents	canals	canals	River	River
	Max	UCL 95 %	Max	UCL 95 %	Max	UCL 95 %
Acetaminophen	56.6	43.19	711.0	237.70	1100.0	1126.27
Acetylsalicylic acid	553.0	496.31	22300.0	6807.55	16.0	14.48
Atenolol	46.0	42.06	278.0	120.76	1.2	1.27
Caffeine	1250.0	819.69	2860.0	1791.22	117.0	110.87
Chlorampenicol	2.8	2.72	7.7	3.75	0.0	0.00
Ciprofloxacin	74.3	59.89	194.0	85.57	47.7	39.98
Diclofenac	92.6	90.35	209.0	111.42	8.9	8.67
Enrofloxacin	1.4	1.22	1.9	1.42	1.9	1.98
Fenbendazole	0.5	0.50	0.6	0.39	0.0	0.00
Ibuprofen	62.9	62.93	1030.0	470.25	25.7	25.42
Lincomycin	5.1	4.96	15.5	5.57	0.0	0.00
Mefenamic acid	296.0	290.80	843.0	471.66	18.0	17.72
Naproxen	57.7	43.99	481.0	166.37	3.2	3.05
Roxithromycin	13.6	11.25	10.0	5.25	5.4	4.89
SMX	12.4	12.50	16.9	11.77	0.8	0.81
SMZ	47.4	35.04	65.8	25.10	3.5	3.38
STZ	35.8	32.51	221.0	90.98	2.8	3.29
Trimethoprim	15.9	14.00	75.4	34.73	2.7	2.35

Table A.3 MEC values used for HQs calculation, during January 2012 sampling event

Pharmaceuticals	Effluents	Effluents	canals	canals	River	River
	Max	UCL 95 %	Max	UCL 95 %	Max	UCL 95 %
Acetaminophen	39.6	31.78	260.0	89.86	91.5	100.22
Acetylsalicylic acid	132.5	110.79	183.0	93.47	14.5	13.49
Atenolol	59.4	48.01	79.3	44.73	3.9	3.87
Caffeine	441.5	340.36	932.5	546.43	179.0	181.07
Chlorampenicol	1.2	0.76	1.6	0.66	1.2	1.01
Ciprofloxacin	71.7	69.89	76.2	43.78	0.0	0.00
Diclofenac	177.0	146.35	118.5	84.58	19.1	18.32
Enrofloxacin	2.5	1.60	6.3	2.04	0.0	0.00
Fenbendazole	0.0	0.00	0.0	0.00	0.0	0.00
Ibuprofen	125.5	108.68	523.0	268.27	43.9	44.81
Lincomycin	2.7	1.92	4.9	2.02	0.0	0.00
Mefenamic acid	254.5	237.90	262.5	182.06	24.5	24.97
Naproxen	64.2	60.88	114.0	62.88	5.2	5.03
Roxithromycin	41.4	34.47	21.2	13.94	2.6	2.63
SMX	25.0	19.30	12.2	9.87	1.9	1.95
SMZ	22.5	22.47	15.5	13.30	5.3	5.12
STZ	90.1	76.86	118.5	71.29	5.0	5.85
Trimethoprim	24.7	20.84	29.9	19.42	2.3	2.36
OTC	0.0	0.0	413.8	152.45	0.0	0.0

BIOGRAPHY

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PUBLICATIONS/PRESENTATIONS

1. **S. Tewari**, R. Jindal, Ying Li, Y. L. Kho and K. Choi. (2011). ‘occurrence and fate of some pharmaceutical residues in sewage treatment plants and receiving water in seoul, south korea”. 4th International Congress of Environmental Research (ICER-11), 15 - 18, December 2011, Surat, India

2. **Shruti Tewari**, Ranjana Jindal, Young Lim Kho, S. Mi Eo and Kyungho Choi. “Occurrence and Potential Ecological Risks of Major Pharmaceutical Residues in Wastewater Treatment Plants and Receiving Waters in Bangkok, Thailand”. (Manuscript is ready to be submitted to an international journal).