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WATER CONTAMINATION OF URBAN AREASBY PHARMACEUTICALS

Abstract. The occurrence and fate data of pharmaceuticals in the environment were described in the article. The main list of pharmaceuticals groups identified in surface and sewage waters was shown according to studies of laboratories in the U.S. and Europe. The main approaches for reduction of pharmaceuticals releasing into environment and monitoring of surface water were considered.

Introduction. Nowadays the pharmaceutical industry and pharmacy is one of the most highly developed complexes of industry in the world, which increases the quality of life and socio-economic indicators in the society.

At the same time, the 50% of inhabitants in the world live in cities. Two-thirds of the world's population will live in urban areas by 2025. Moreover, the number of megalopolises (with population over 10 million people) also will increase from 21 to 29 by this time.

This entails global demographic, epidemiological and economic changes. The biggest non-infectious epidemic in the world is diabetes, now there are 366 million of patients. According to epidemiological data, in 2030 there will be more than 552 million people suffering from this disease in the world (http://zdorov-info.com.ua/). In accordance to data (http://www.oecd-ilibrary.org/) in 2009 the consumption of antidiabetes drugs reached 2.3 tons in Germany and 1.5 tons in UK. The basic annual consumption data of certain pharmaceutical groups in different countries is presented in Figure 1. Thus, the manufacturing of pharmaceuticals has reached an extremely high level, and by the latest consumption forecasts will be more than 100 thousand tons per year in the world.

The main aim of this paper was summarizing the existing studies and occurrence data of pharmaceuticals in the environment. Based on these data the actual research areas and regulatory issues (e.g. monitoring, control and management) of pharmaceuticals were discussed for perspective.

2 Pharmaceuticals in the environment. Because of the global production and consumption of drugs, an extensive investigation of releasing pharmaceuticals mechanisms and changes into environment is being performed.

According to the results of the research (McClellan, 2010; Bendz, 2005;Boxall, 2004) the remnants of drugs and their derivatives are found in surface waters in France, USA, UK, Germany, Denmark and Sweden. These substances also can be found in sewage sludge, river and ocean sediments and in the municipal landfills filtrates. Some species have been found even in drinking water and ice, ground and ocean waters.

Many studies confirmed the data of the annual drug releasing into the environment, which counts several hundred of kilograms. The study (Saussereau, 2013) demonstrates the annual dumping 75.6 kg of drug Celiprolol, 38 kg of Tramadol, 31.9 kg of Oxazepamin the River Seine.

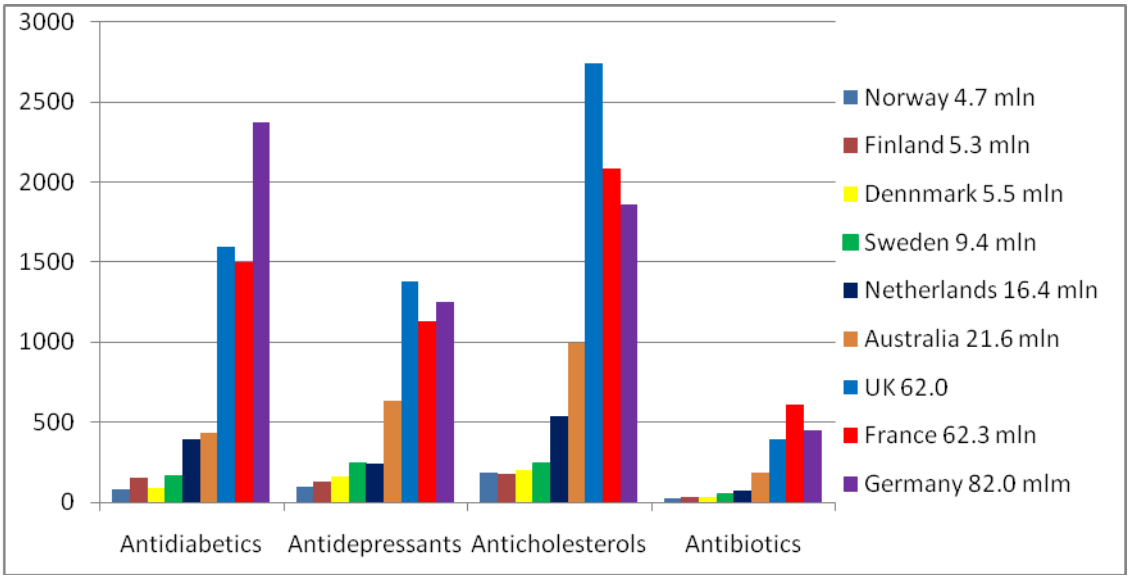

Figure 1 – The annual consumption of different pharmaceuticals groups in the world, kg / year

Such a large amount of pharmaceuticals in the environment can be explained by the fact that not all used drugs for human and animals treatment go through biotransformation in the body. According several studies for this process exposed from 5 to 95% of all medicines (Kummerer, 2010, KummererK, 2000).

2.1 Pharmaceuticals in surface waters. Currently in the waters of Europe more than 3,000 kinds of pharmaceutical shave been found. For instance, recent monitoring of the rivers in Baltic Sea countries demonstrated containing up to μg l^{-1} concentrations of drugs. It concerns also the Baltic Sea, the waters of which washes the shores of Russia, Estonia, Latvia, Lithuania, Poland, Germany, Sweden, Denmark and Finland.

Oxazepam (a benzodiazepine) has been detected near the coast of Stockholm at concentrations of 15–20 ng l^{-1} (HELCOM, 2010). Table 1 shows the data of the presence of pharmaceuticals residues in the natural waters according to references.

Concentrations of certain pharmaceuticals were also found in fish and other aquatic organisms. Thus, Baltic Sea salmon has been found to contain 17α-ethinylestradiol at a concentration of 0.90 µg kg^{-1}. In the Swedish screening study the antibiotic substance Ciprofloxacin was found in three out of five fish samples, with an average concentration of 6 µg kg^{-1} (HELCOM, 2010). The investigations of the life cycle of insects have shown that carbamazepine (antiepileptic drug) affects the reproduction of midges (gnats-Zvontsov), water mosquitoes in natural waters (Delorenzo, 2010).

2.2 Pharmaceuticals in the wastewaters. The content of these drugs in the waste water sentering into the municipal sewage treatment plants (STPs) is estimated tens or hundreds of times higher (Table 2).

Table 1 – The concentrations of drugs in the natural waters

Medical class	Substance	Concentrations, µg/l	Removal efficiency,%
Antibiotics	Ciprofloxacin	0.03[4]; 0.025[5]	–
	Norfloxacine	0.12[4]; 0.076[5]	–
	Sulfamethoxazole	1.9[4]; 0.14[5]	–
	Tetracycline	0.11[5];	–
Anti-inflammatory drugs	Diclofenac	1.0[4]; 0.81[5]	17–69
	Naproxen	0.39[4]; 0.074[5]	66–93
	Ibuprofen	3.4[5];	90
Antiseptic	Triclosan	0.15[3]; 2.3[9]	55–95
β-blockers	Bisoprolol	2.9[4,5]	–
	Metoprolol	2.2[4,5]	83

[3,4,5,9] – referencenumber

4 Removal of pharmaceuticals at STPs. The treatment efficiency at STPs is significantly affected by several factors such as the physico-chemical properties of pharmaceuticals, the treatment processes employed, the age of the activated sludge, the hydraulic retention time (HRT), environmental conditions (temperature and light intensity, dilution of the wastewater by precipitation) and physical properties, including the compound adsorption capacity in the sludge. Many STPs in Europe include only two treatments steps (physical and biological)(Zorita, 2009).In this case activated sludge from STPs is exposed of different pharmaceuticals groups for several years. Therefore, it might have some factors inefficient microbiological removal of these substances from the wastewaters such as the new drugs, which have being released each year on the market. Some of them can belong to the new classes, which microbiota of STPs has never been interacted. It can also be one cause of some difficulties for biodegradation. (Daughton,1999).

Table 2 – The concentrations of drugs in wastewaters

Medical class	Substance	C in wastewater reference, μg/L	C hospital wastewater reference, μg/L
Antibiotics	Ciprofloxacin	0.01[11]; 0.16[12]	3.6[12]; 54[13]
	Norfloxacine	0.01[11]; 0.23[12]	23.0[13]
	Sulfamethoxazole	0.02[11]; 0.05[12]	1,3[12]; 7.1[13]
	Tetracycline	0.02[11]; 0.3[12]	1.5[12]
Anti-inflammatory drugs Antiseptic	Diclofenac	0.16[11]; 5.45[12]	1.6[12]
	Naproxen	0.92[12]	–
	Ibuprofen	0.018[12]	0.9[13]
β-blockers	Triclosan	0.14[11]	–
	Bisoprolol	0.16[11]	2.2[13]
	Metoprolol	0.2[11]	–

[11, 12, 13] – referencenumber

5 The main sources of water pollution. The main sources of water pollution by pharmaceuticals and their derivatives are wastewater from hospitals, clinics, pharmaceutical industries and domestic sewage as well. However, the main percentage of pharmaceuticals dumped into wastewaters is coming for the hospitals. This is typical for large cities, where is situated a great number of hospitals and health care institutions. In the opinion of study (Zgorska, 2011) hospital wastewaters have in a 15 times higher potential ecotoxicity than the general urban have.

In accordance to investigation of 73 pharmaceuticals from 12 different therapeutic classes, reveals that these compounds are found in consistently higher concentrations in hospital wastewaters than in urban sewage, particularly commonly used drugs such as analgesics and antibiotics (See table 2). In addition, they confirm that antibiotics are one of the most critical therapeutic classes used in hospitals, being highly resistant to degradation and removal (Verlicchi, 2012).

6 The situation in different countries. Unfortunately, nowadays in post-Soviet countries and as in Ukraine insufficient attention is given to studies of pharmaceuticals pollution and their impact on the environment. Currently in these countries, it is unknown real extent of water pollution by these substances. Therefore, the authors have calculated the concentrations of drugs in wastewater before and after treatment at STPs in Kharkov (Ukraine) (Table 3).

Table 3 – Comparative analysis of calculated and measured concentrations of the pharmaceuticals to different types of flow formation

Name of drug substance	C_{cal} in wastewater μg/L		C_{meas} In river Uda in Kharkiv, μg/L	C_{meas} in wastewater reference μg/L	Removal efficien-cy,%
	Kharkiv	reference			

Metoprolol	0.03–0.59	0.17[13]	–	0.08–0.71[4,13]	83[4]
Diclofenac	0.37–6.39	0.1–5.4[4,17,18]	0.23–0.65[19]	0.16–3.4[4,13,17,19]	9–60[4,17,19]
Ketoprofen	0.56–9.57	0.2–0.4[18]	0.25[19]	0.94–2.6[4,18]	15–98[4,18,19]
Ciprofloxacin	2.1–35.8	–	–	0.038–54[13]	–
Ibuprofen	0.33–5.62	3.1–19.8[17,18]	0.021[19]	0.5–17[4,13,17,18]	66–93[4,18,19]

[4, 13, 17, 18, 19] – reference number

The calculated theoretical concentrations of pharmaceutical in the wastewaters are good coinciding with measured concentrations. The theoretical concentrations of Diclofenac and Ketoprofen are correlated on 88–89% with the determined concentrations of instrumental way in the surface waters of the Uda River in Kharkov, Ukraine. The obtained convergences of the results are agreed with literature data for the corresponding type of calculations (Muthanna, 2008).

7 The monitoring of pharmaceuticals. Monitoring of quality water resources, made by the State, usually involves an integrated approach and determination of organic pollutants such as phenol, benzene, xylene, toluene, methanol etc, but there is absent the list of pharmaceuticals measurements for the sewage and surface waters.

Today, the European Commission of the EU Framework Directive for Water, 2000/60/EC proposed only four pharmaceuticals drug (diclofenac, ibuprofen, and ethinylestradiol estradiol) as candidates to be included in the list of priority substances (followed by controlling release into the environment) (Falås P., 2012).Among the substances that have also enough data to classify them as hazardous for the aquatic environment and requiring for monitoring are diclofenac, ethinylestradiol, ibuprofen, ivermectin, metoprolol, norethisterone, oxytetracycline, tylosin and paracetamol.

Taking into account this fact, it is necessary to monitor natural water in national and also in the international framework. It is required the development of especially common monitoring policy for that common natural waters in which are dumped wastewaters and for which made drinking water abstraction. It should be also important for countries, where all major rivers are the transboundary (Western Dvina, Dnepr, Seversky Donets and Don).

8 Treatment methods. According to the properties of pharmaceuticals and their derivatives scientists have developed and applied different treatment methods for removal resistant organic molecules from wastewaters:

1) filtration (use of membranes, micro-filters, ultrafiltration);

2) sorption (mineral and molecular polymers, activated charcoal);

3) oxidation;

4) biological treatment.

But there is no universal method guaranteeing for a treatment of all pharmaceuticals and the removal of the most stable drugs molecules will be still low (Vystavna, 2012).

For example, removal rates on the Membrane bioreactor (MBR) treatment ranged from 55% to 80% for different groups of antibiotics (Schroder H. Fr., 2012). Therefore, persistent pharmaceuticals in small concentrations are discharged from the wastewater into the environment. This discharge could be reduced with the application of additional post treatment steps using advanced treatment techniques, e. g., adsorption on activated carbon, ozone oxidation or advanced oxidation processes(AOP) (Schroder 2012).

9 Conclusion and recommended interventions. The water pollution by pharmaceuticals is the issue of the day.

Essentially, the investigations of negative impact of pharmaceutical substances and their derivatives on aquatic organisms have been performed during more than 15 years and showed an extremely negative presence of any drugs in the waters.

Therefore, the implementation of AOP for wastewater treatment can be used on the local levels including hospitals and other medical institutions. Also, this can be used for sewage water purification of modern apartment building and it should be considered in the design and construction of household sewage systems.

Summing it up, the actual research areas can be:

– studying the sources of pharmaceuticals pollutants and determination of their concentrations in the wastewaters;

– estimation of drug influence on the waters and organisms;

– developing the methods of improving the wastewater efficiency from micropollutants at the STPs;

– development the technologies of the local wastewaters treatment contained hard biodegradable substances;

– extension of the research and improvement of monitoring of natural waters related to the presence of pharmaceuticals.

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