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Pharmaceuticals In The Water Supply

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Abstract

Pharmaceutical products & their wastes play a major role in the degradation of environment. These drugs have positive as well as negative consequences on different environmental components including biota in different ways. Many types of pharmaceutical substance have been detected with significant concentrations through various advanced instrumental techniques in surface water, subsurface water, ground water, domestic wastewater, municipal wastewater & industrial effluents. Several committees were formed to research, check & assessing risk associated with the pharmaceutical substance concentration present in the water but no strong regulation was implemented on industries. However, government promote pharmaceutical industries without proper assessing the risk. As a result, pharmaceutical companies are producing different types of pharmaceutical products at large scale & also producing complex non-biodegradable toxic wastes byproducts & releasing untreated or partially treated wastes in the environment in absence of strong regulation.

Keywords: Traces of Pharmaceuticals, wastewater treatment, TDI, drinking water.

1.0 Introduction

In the last decade, traces of pharmaceuticals, typically at levels in the nanograms to low micrograms per litre range, have been reported in the water cycle, including surface waters, wastewater, groundwater and, to a lesser extent, drinking-water. Advances in analytical technology have been a key factor driving their increased detection. Their presence in water, even at these very low concentrations, has raised concerns among stakeholders, such as drinking-water regulators, governments, water suppliers and the public, regarding the potential risks to human health from exposure to traces of pharmaceuticals via drinking-water [1].

Researchers have formed organizations to work on the problem of increasing levels of pharmaceutical compounds in water. One of the major organizations is known as Silent Spring, named after the book Silent Spring by Rachel Carson. The organization was formed in 1994 and its major cause is to study the environment in an attempt to discover environmental causes of cancer. The research focus of this group includes looking at pharmaceuticals in streams, lakes, underground reserves and wells, and in drinking water [2]. Following requests for information regarding the potential health impacts of residual concentrations of pharmaceuticals in drinking water, this issue was added to the work plan of the World Health Organization (WHO) Drinking-water Quality Committee in 2005. It was proposed that a working group of experts be assembled to undertake a rapid review of the state of the science of pharmaceuticals in drinking-water and develop guidance and recommendations in a report and fact sheet.

A WHO working group that comprised experts in toxicology, water chemistry, water quality and health, water treatment, pharmacology, and drinking-water regulation and policy was formed in 2009. Consultations were held in 2009 and 2010 with the Drinking-water Quality Committee and additional experts to review and summarize the available scientific knowledge and evidence.

In 2008, the Associated Press (AP) found an array of pharmaceuticals, from pain killers to antibiotics to mood stabilizers, in the drinking water of 24 major metropolitan water suppliers. Further, 34 of the 62 water suppliers contacted by the AP

couldn't provide results as they had never tested for pharmaceutical compounds [3]. Through many tests, researchers have collected various pieces of data on the effects these pharmaceuticals have, but because of the large number of variables in the different chemicals they cannot accurately estimate the full threat. Another reason for the lack of data is when pharmaceuticals go through the treatment process they may be changed or chemically modified to form a new product that can be potentially harmful.

2.0 Occurrence of pharmaceuticals in water

Pharmaceuticals are synthetic or natural chemicals that can be found in prescription medicines, over-the-counter therapeutic drugs and veterinary drugs, and they contain active ingredients that evoke pharmacological effects and confer significant benefits to society. The ubiquitous use of pharmaceuticals in human and veterinary medical practices, aquaculture and agricultural products has led to the continual release of a wide array of pharmaceutical chemicals into our environment. As illustrated in Figure 1, pharmaceuticals enter the environment through many routes, including human or animal excreta, wastewater effluent, treated sewage sludge, industrial waste, medical waste from health-care and veterinary facilities, landfill leachate and biosolids.

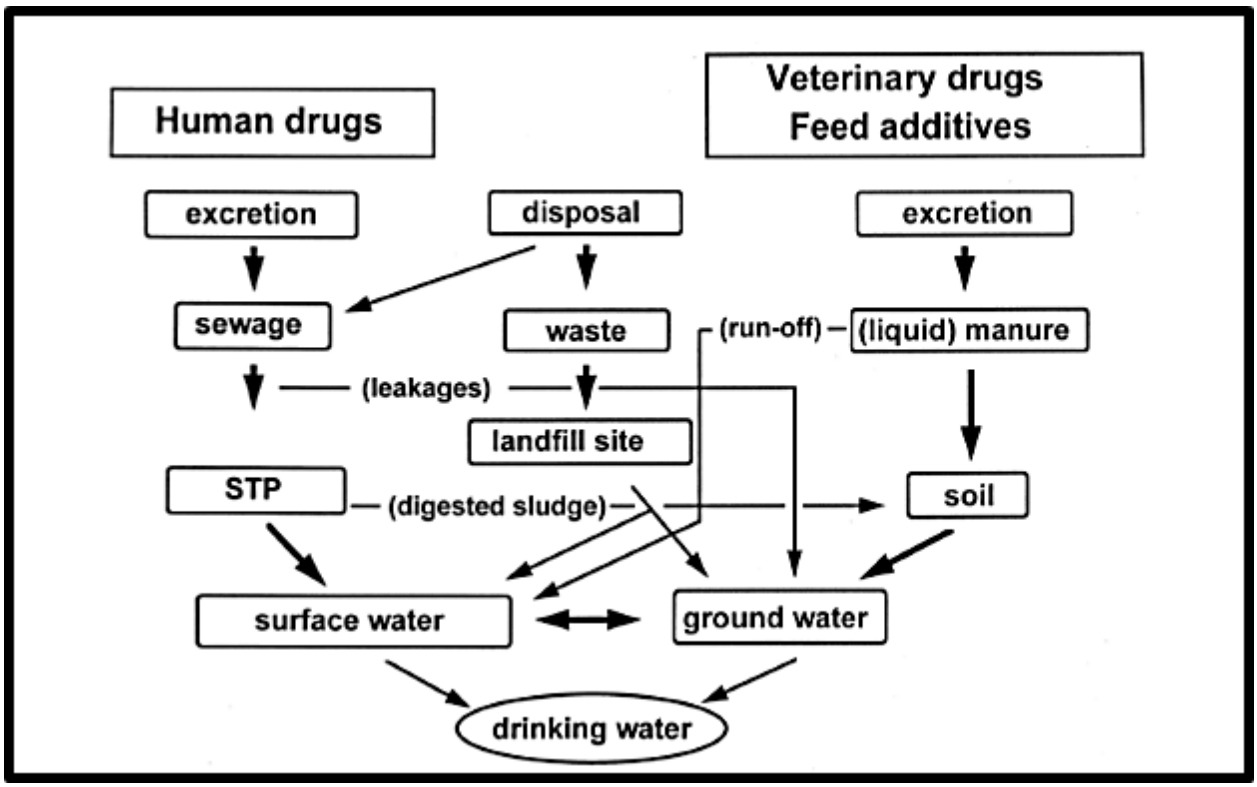

Figure 1: Sources of drug in water

Pharmaceuticals and their metabolites undergo natural attenuation by adsorption, dilution or degradation in the environment, depending on their hydrophobicity and biodegradability and on the temperature. Therefore, pharmaceuticals in water sources and drinking-water are often present at trace concentrations, as these compounds would have undergone metabolism and removal through natural processes and, if applicable, wastewater and drinking-water treatment processes. Amounts of pharmaceuticals and their strength are increasing due to the increase of the human population and their reliance on medications [4]. The pharmaceutical industry has to try and sell its products to people and "a customer-oriented culture allows a firm to achieve customer satisfaction, increase customer loyalty, and attract new customers." [5].

2.1 Advances in analytical and detection methods

The increase in reported detections of very low concentrations of pharmaceuticals in various environmental matrices, including the water cycle (e.g. surface water, groundwater, treated wastewater effluent and drinking-water), is mainly attributable to technological advances in the sensitivity and accuracy of detection equipment and analytical methods. Gas chromatography with mass spectrometry (GC-MS) or tandem mass spectrometry (GC-MS/MS) and liquid chromatography with mass spectrometry

(LC-MS) or tandem mass spectrometry (LC-MS/MS)1 are advanced methods that are able to determine target compounds to the nanogram per litre level and are commonly applied for the detection of pharmaceutical compounds in water and wastewater. The selection of methods is dependent on the physical and chemical properties of the target compound. LC-MS/MS analysis is more suitable for measuring target compounds that are more polar and highly soluble in water, whereas GC-MS/MS is better for more volatile target compounds [6].

2.2 Occurrence of pharmaceuticals in surface water

Scientists demonstrated the presence of pharmaceuticals in the environment more than 30 years ago, with studies in the United States of America (USA) in the 1970s that reported the presence of heart medications, pain relievers and birth control medications in wastewater [7, 8]. The most cited reference in the peer-reviewed literature on the occurrence of pharmaceuticals in surface waters is the survey by the United States Geological Survey, in which more than 50 pharmaceuticals in 139 streams across 30 states in USA were investigated during 1999 and 2000 [9].

Many peer-reviewed and published studies have shown that the primary sources of pharmaceuticals entering surface water are from excretion and bathing through treated or untreated municipal wastewater effluent discharges into receiving surface water bodies [9, 10, 11] and improper disposal of pharmaceutical waste and excess medication by consumers and health-care and veterinary facilities into sewers and drains. Table 1 illustrates several classes of pharmaceuticals found in wastewater influent in a study conducted by the Drinking Water Inspectorate in the United Kingdom.

Table 1: Excretion rates of unmetabolized active ingredients for selected pharmaceuticals [12]

Compound	Pharmaceutical product group	Parent compound excreted (%)	Reference
Amoxycillin	Antibiotic	60	[13]
Atenolol	Beta blocker	90	[13]
Bezafibrate	Lipid regulator	50	[13]
Carbamazepine	Antiepileptic	3	[13]
Cetirizine	Antihistamine	50	[13]
Clofibric acid	Active metabolite	6	[14]
Diclofenac	Anti-inflammatory	15	[14]
Erythromycin	Antibiotic	25	[13]
Felbamate	Antiepileptic	40-50	[13]
Ibuprofen	Analgesic	10	[13]

2.3 Occurrence of pharmaceuticals in drinking-water

Most countries (if any) do not have monitoring programmes to routinely test for pharmaceuticals in drinking-water owing to practical difficulties, such as high costs and lack of availability of routine analytical technologies and laboratory infrastructure to detect a diverse range of pharmaceuticals and their metabolites. As a result, the majority of the occurrence data for pharmaceuticals in drinking-water and surface waters come from targeted research projects, targeted investigations and ad hoc surveys, most of which were designed to develop, test and fine-tune detection and analytical methods. Nevertheless, they did provide an initial indication of the presence of pharmaceuticals in the environment.

Studies in the USA have detected very low levels of pharmaceuticals in finished drinking-water. The highest concentration reported was 40 ng/l for meprobamate [15]. Studies have also found several pharmaceuticals in tap water at concentrations ranging from nanograms to low micrograms per litre in several countries in Europe, including Germany, the Netherlands and Italy [16]. Two separate studies in Germany [17, 18] found phenazone and propyl phenazone (an analgesic and an antipyretic drug, respectively) in Berlin drinking-water, with the highest concentration being 400 ng/l for phenazone. This high value was largely attributed to groundwater, used as a drinking-water source, contaminated with sewage [19]. In the Netherlands, traces of antibiotics, antiepileptics and beta blockers were detected in the drinking-water supply at concentrations below 100 ng/l, with most concentrations below 50 ng/l [20].

3.0 Human health risk assessment for pharmaceuticals in drinking-water

Concern has been raised, however, because exposure to pharmaceuticals through drinking water is an unintended and involuntary exposure over potentially long periods of time. Moreover, there are few scientific risk assessments of exposure to low levels of pharmaceuticals, both as individual species or as mixtures, in drinking water.

3.1 Assessing risks associated with pharmaceuticals in drinking-water

Chemical risk assessment methods for substances found in food and drinking-water involve establishing an acceptable daily intake (ADI) or tolerable daily intake (TDI) based on a variety of calculations (e.g. from extrapolations, applications of uncertainty factors) applied to a selected point of departure (PoD) from the toxicological and epidemiological database. A common and widely accepted PoD is that concentration at which no adverse effects are detected, which is the no-observed adverse-effect level (NOAEL), or, less optimally, the lowest concentration at which adverse effects are detected, which is the lowest-observed-adverse-effect level (LOAEL), in combination with an additional uncertainty factor. The PoD may also be derived through a benchmark dose based on statistical evaluation of the dose– response curve of the critical study [21].

Health risks from pharmaceuticals in water have been most frequently assessed using the minimum therapeutic dose (MTD, the lowest concentration that evokes a desired therapeutic effect among target populations) as the PoD [12, 22]. This is due to practical reasons, including the lack of readily available toxicological data in the public domain that would be necessary to derive a NOAEL/LOAEL or benchmark dose. The MTD is usually a dose below those concentrations where, in rare instances, unacceptable adverse or toxic effects are observed. Therefore, the use of the MTD as a PoD for risk assessment would often result in the development of conservative screening values.

3.2 Applying the MTD approach: a Drinking Water Inspectorate study

The Drinking Water Inspectorate for England and Wales commissioned a comprehensive desk-based review of current knowledge on and estimation of potential levels of 396 pharmaceuticals and 11 illegal drugs in drinking-water in the United Kingdom based on specific demographic and usage data on active pharmaceutical ingredients and using modelled concentrations based on actual catchments. The DWI (2007) approach was to determine an MOE for each pharmaceutical by comparing the MTD with the theoretical maximum intake from drinking-water. The MOE for each of the targeted pharmaceuticals was derived by comparing the maximum estimated concentrations in drinking-water with the MTD. The results allow an assessment of the significance of individual pharmaceuticals through drinking-water exposure.

The DWI (2007) study led to the conclusion that majority of the pharmaceuticals had MOEs greater than 1000, suggesting a substantial margin of safety against potential adverse health impacts from exposure to trace concentrations of pharmaceuticals in drinking-water.

3.3 Applying the ADI approach [23]

The Awwa Research Foundation commissioned a study to provide critical information regarding the occurrence of and risk assessment for pharmaceuticals and potential endocrine disrupting chemicals (EDCs) in drinking-water. The study examined 62 chemicals, including 20 pharmaceuticals and active metabolites, 26 potential EDCs, 5 steroid hormones and 11 phytoestrogens (natural oestrogens from plants). The health value applied in this study was the ADI, and a conservative approach was taken in the process of developing the ADI values, as illustrated in table 2.

In this study, the ADIs were converted to drinking-water equivalent levels (DWELs) in micrograms per litre (or parts per billion) based on assumptions of a 70 kg body weight in adults and consumption of 2 litres per day.

Table 2: Principles for deriving ADIs for compounds considered in this study

Category of analytes	Derivation of ADIs
Compounds that are not carcinogenic	Dividing the highest dose at which an effect was not observed (NOAEL) or the lowest dose at which an effect was observed (LOAEL) in animal or human toxicity studies by uncertainty factors to account for extrapolation to potentially sensitive populations
Compounds with positive evidence of carcinogenicity in high-dose animal studies and data on tumour incidence per dose level	A linear extrapolation model was used to predict the tumorigenic response at low dose level
Carcinogenic compounds with reported evidence in animal studies, but no available tumour incidence data	A safe dose corresponding to a cancer risk of one in a million was estimated

4.0 Treatment technologies for removal of pharmaceuticals from water

Many studies have reported the presence of pharmaceuticals in effluents from wastewater treatment facilities [11, 24], and identified these effluents as the main conveyors of pharmaceuticals and their metabolites into receiving water sources, such as rivers, lakes, reservoirs and groundwater aquifers, that are used for drinking-water supply [3, 25, 16].

4.1 Removal of pharmaceuticals by wastewater treatment processes

Conventional wastewater treatment facilities typically have biological degradation using the activated sludge process, whereas advanced facilities have tertiary treatment processes, such as reverse osmosis, ozonation and advanced oxidation technologies. Pharmaceuticals are a diverse group of chemicals, with varying physical and chemical properties [26]. Treatment efficacy depends on these physical and chemical characteristics (e.g. hydrophobicity), their reactivity towards different treatment processes and process control, such as solids retention time, temperature and hydraulic retention time. For example, the majority of pharmaceuticals are relatively hydrophobic and therefore less effectively removed by sorption to sludge. Treatment removal efficiency could therefore vary significantly between different treatment facilities or at different time periods within the same treatment facility [27].

4.2 Removal of pharmaceuticals by drinking-water treatment processes

Treated effluents from wastewater treatment facilities that have an impact on receiving water bodies constitute the main source of pharmaceuticals in surface waters, which could be used for drinking-water supply [28]. Other possible pathways of pharmaceuticals to drinking-water sources include leaching of pharmaceuticals to groundwater [29] from sources such as leaking sewage systems and pipes.

5.0 Preventing pharmaceuticals in drinking-water

Conventional drinking-water quality monitoring that places emphasis on end-product testing is very resource intensive in terms of capital investment and human resources. With an expanding list of chemical contaminants detected in drinking-water and water sources that may be of insignificant health concern, an overemphasis on end-product monitoring and the upgrading of treatment infrastructure is clearly not sustainable or an optimal use of limited resources.

Currently, tighter rules and regulations apply to controlled substances and cytotoxic drugs than for other pharmaceuticals. Despite this, disposal to sewers is not precluded [30]. Disposal of non-controlled substances tends to be more variable and is often developed on a local, jurisdictional or regional basis. A scan of the current literature, which is not exhaustive, revealed a few broadly categorized preventive measures in Australia, Canada, the USA and European countries that could potentially reduce the entry of pharmaceuticals into our environment. These measures are described below.

5.1 Improved regulations and guidance on pharmaceutical waste management

All health-care facilities should have policies and procedures in place for the correct management of pharmaceutical waste. In Australia, the Environmental Protection Authority and the National Health and Medical Research Council had guidelines on the management of waste generated in health-care facilities. The National Health and Medical Research

Council stated that, where possible, pharmaceutical waste should be incinerated and should not be sent to landfills or discharged to sewers [31]. Licensed waste disposal companies collected all clinical and pharmaceutical waste for disposal in authorized waste disposal facilities.

5.2 Pharmaceutical take-back programmes

To augment regulations, take-back programmes have been established by government and private organizations in several countries to reduce the number of drugs entering our environment [32, 33]. A survey of households in the United Kingdom in 2003 showed that 22% of excess pharmaceuticals were returned to pharmacists; although take-back programmes were effective, further improvement is needed [13].

These programmes can be of different scales, ranging from small one-day collection events to regular and systematic regional collection, ongoing return of unused and excess medicines to participating pharmacies and mail-back programmes where excess medicines are returned in prepaid packs to government-supervised mailboxes [34]. Several household hazardous waste collection programmes have also added pharmaceuticals to the list over the years [33].

5.3 Raising consumer awareness

Consumers are accustomed to disposing of unwanted and expired medicines through household waste and sewers. Such improper disposal practices release pharmaceuticals into our environment, wastewater and water sources. There is therefore a need to raise public awareness and encourage consumers to adopt proper disposal practices for unwanted pharmaceuticals. In Australia, the RUM Project focuses on raising consumer awareness to inform consumers of the appropriate option for drug disposal [35]. In addition to regulations under New York's Drug Management and Disposal Act, the New York State Department of Environmental Conservation publishes posters for all pharmacies and retail stores that sell drugs to advise consumers on the proper storage and disposal of unwanted medication [36]. Consumers can then serve as environmental stewards to reduce water pollution.

6.0 Conclusion

Targeted investigative studies conducted in the United Kingdom, the USA and Australia have shown that concentrations of pharmaceuticals in surface water and groundwater sources impacted by wastewater discharges are typically less than 0.1 µg/l (or 100 ng/l). Detection in treated drinking-water is rare; if pharmaceuticals are present, their concentrations are usually well below 0.05 µg/l (or 50 ng/l). There are, however, very few systematic monitoring programmes or comprehensive, systematic studies on the occurrence of pharmaceuticals in drinking-water, and limited occurrence data present one of the key challenges in assessing the potential risks associated with trace concentrations of pharmaceuticals in drinking-water. Targeted investigations found that traces of pharmaceuticals in drinking-water are largely present at several orders of magnitude (more than 1000-fold) below the lowest therapeutic dose and largely below the calculated ADIs. The substantial margins of safety for individual compounds suggest that appreciable adverse impacts on human health are very unlikely at current levels of exposure in drinking-water.

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