Applied Water Science (2018) 8:199
https://doi.org/10.1007/s13201-018-0846-z

REVIEW ARTICLE

Antibiotics in wastewaters: a review with focus on Oman

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Received: 7 September 2016 / Accepted: 5 October 2018 / Published online: 15 October 2018

Abstract
The occurrence of antibiotics in treated wastewater effluent has been a concern worldwide for various reasons: most importantly development of antibiotics resistance by bacteria and other microorganism, impact of antibiotics on animal life in surface water and likely consequences on humans if treated wastewater is used for drinking water supply through the process of managed aquifer recharge (MAR). Another potential area of concern is the uptake of these antibiotics by crops irrigated by treated wastewater. In Oman, wastewater treatment and reuse is pursued vigorously as a government policy. Treated wastewater is used for crop irrigation following government regulations, MAR is being contemplated and practiced in small scale and release of such waters in the ocean takes place from time to time. Some tests have been conducted on the wastewater effluent around the world to verify and detect the concentration of antibiotics in wastewater effluent. In the Sultanate of Oman, very little research has been performed on the occurrence of antibiotics in treated wastewater, removal efficiencies of treatment processes and development of antibiotics resistance. It is expected that wastewater reuse will increase substantially due to expansion of sewerage network in the capital city as well as many other cities and towns. As such, it is imperative that research be undertaken to find out various issues related to commonly used antibiotics such as ciprofloxacin, norfloxacin, erythromycin, linezolid, penicillin, ampicillin, chloramphenicol, streptomycin, minocycline, tetracycline and sulfamethoxazole in Oman and their ultimate fate through the treatment process. In addition, the development of guidelines is crucial in amounts of antibiotics acceptably occurring in treated wastewater effluent and if they could be suitable for agriculture without causing any harm. A review of the available literature and data are provided in this article. Research needs have been identified.

Keywords Antibiotics · Occurrence · Wastewater · Treatment · Reuse · Oman

Introduction

Antibiotics are a type of pharmaceuticals used in the treatment of human and veterinary medicine. They inhibit the growth of different types of microorganisms for different diseases (Lindberg 2006). They were first discovered in the 1940s, starting with penicillin, which was coincidentally found to be produced by a fungus, later more antibiotics were developed from soil bacteria and now more antibiotics are synthesized antibiotics (Clardy et al. 2009).

Penicillin (a group of β-lactams) is the most common and oldest antimicrobial, which include naturally occurring (penicillin G), aminopenicillins (ampicillin) and extended-spectrum (piperacillin). This penicillin group target to destruct the bacterial cell wall by destroying or inhibiting the production of peptidoglycan, which is one of the main components for cell wall synthesis (Hauser 2012). The presence of the antibiotic residues in the sewage treatment plants poses a problem due to the reasons such as increased risks to human health from the development of antibiotic-resistant microorganisms if antibiotics are present in sublethal concentrations of the pathogens in sewage (Al-Bahry et al. 2013).

In addition, the associated environmental health effects of antibiotics toward aquatic wildlife decrease in the sewage or wastewater treatment efficiency by changing in the concentrations of the active biomass involved in the secondary or tertiary sewage treatment due to exposure to antibiotics (Robinson et al. 2005; Kraigher et al. 2008). On the other hand, risks to human health and decreased treatment

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efficiency ultimately increase the cost of public and private health care for any given country in the world (Islam 2013).

Antibiotics work by inhibiting the growth of bacteria and its replication in different ways, which includes that of inhibiting the synthesis of the cell wall and the deoxyribonucleic acid. In the majority of the cases, antibiotics destroy the microorganisms, for example inhibiting the bacterial growth and allowing the recovery of the person or animal. There are different mechanisms of action for each class of antibiotic, which is also dependent on the target. The secondary treatment of wastewater is often based on the bacterial activity such as the activated sludge process; the existing facilities are often not designed completely to remove antibiotic residues from the sewage through the treatment process (Islam 2013).

Drug resistance could occur with fluoroquinolones by a mutation that changes the drug target (Blondeau 2004). Antibiotics such as macrolides (azithromycin and erythromycin) work on the ribosomes; they bind to 50S subunit of the ribosomes of the bacteria and inhibit its protein synthesis, leading to cell death, while trimethoprim and sulfamethoxazole inhibit important enzymes responsible for the biosynthesis of nucleic acid into dihydrofolate reductase and dihydrofolic acid (LexiCOMP 2016).

In this context, the current review is an attempt to provide an updated short review on the occurrence of antibiotics in the wastewater systems of Oman. The focus of review is on antibiotic consumption by human and their physicochemical properties and dynamics in the environment and systems of wastewater treatment related to Oman. Moreover, the knowledge gaps in the currently available information on antibiotics are identified and discussed along with this literature review.

Methodology

This paper is based on a literature review of texts and references sourced from policy documents, and published and unpublished reports. In order to reflect the overall status of antibiotics research in the environment focused on wastewater systems of Oman, a systematic literature review was performed using an electronic search of Web of Science (published in ISI), PubMed, Elsevier, Springer and Google Scholar. Literature published with focus on Oman was retrieved from the Ministries Web site. In addition, the literature review was also considered master's thesis and doctoral dissertation. It is imperative to mention that given the large number of studies that are available in the scientific literature, our review focused mostly on that scientific knowledge that was most related and important to the occurrence of antibiotics in wastewater environment. Therefore, secondary sources and reviews of published literature used in this article would form valuable indirect information on antibiotic focused in Oman.

Pathway of pharmaceuticals in the environment

Over the recent years, antibiotics are being considered as an emerging class of contaminants in the environment since they have been widely used in human and veterinary medicine and present in the environment through a complex cycle of transformation as well as bioaccumulation (Carvalho and Santos 2016). Antibiotics origin in the environment is divided into different sources such as humans, animals, agriculture, aquaculture and pharmaceutical manufacturers. It is mostly evident that humans are the most consumers of antibiotics and share great responsibility in antibiotics ending up in wastewater. Flushing down unused medications including antibiotics, in the toilets, could lead to accumulation of hefty amount of drugs in wastewater. In most houses around the world, there are bunch of medications that are stocked in cabinets and eventually get expired, which ends up to be flushed in the toilets (Harvard Health Letter 2011). Hospital effluent is also rich in antibiotics and in higher concentrations (Kummerer 2009). In addition, drug properties could affect the amount of drugs in wastewater. Drug metabolism could be one of the sources of drugs in wastewater. When a person or animal takes an antibiotic, the body metabolizes it to different chemicals, and only a small portion of it used by the body, while the rest excreted through urine and stool, which ultimately ends up in wastewater (Harvard Health Letter 2011). Another property that aids the accumulation of drugs in wastewater is their solubility. Most drugs are highly soluble in water and readily excreted, which makes it likely that ingested drugs will be transformed by the time they reach environment in varied quantity (Gulkowska et al. 2007) (Fig. 1).

Drug manufacturers could be another source of antibiotics in wastewaters, as waste products; many drugs could be precipitated (Gulkowska et al. 2007), but manufacturers should follow good manufacturing practice (GMP) regulations; thereby, no active drug would be emitted as a waste product and the amount could be insignificant (Kummerer 2009). On the other hand, the wastewaters generated specifically from the activities of agriculture, and aquaculture has not much of an input of antibiotics into the environment (Kummerer 2009).

Wastewater treatment plants in Oman

Oman and the Gulf countries have shortage in the abundance of water as the rainfall seasons are minimal in these countries. There are limited resources of freshwater, making it

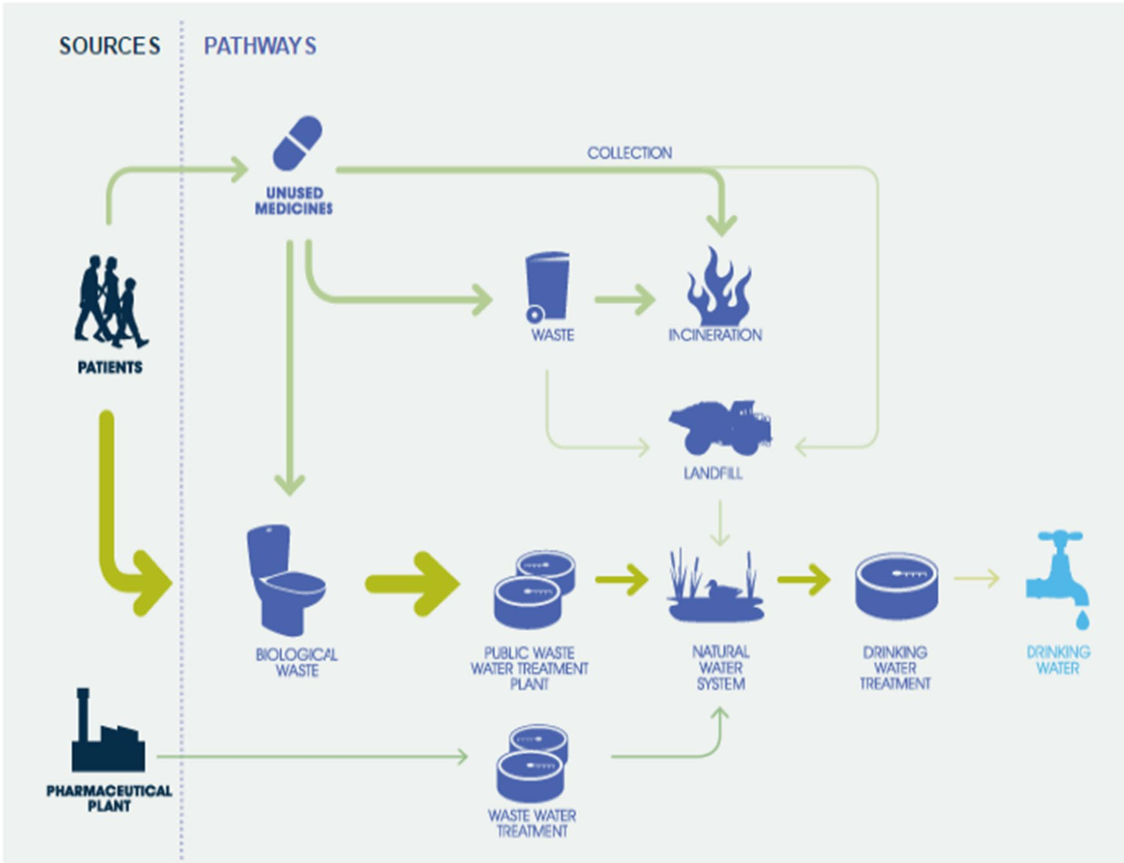

Fig. 1 Main sources and pathways of pharmaceutical residues in the environment (Sanofi 2016)

a huge challenge for agriculture in these countries to cover the least requirements and limiting its varieties. Therefore, it makes for Oman and other Gulf countries desperate to reuse wastewater through wastewater treatment plants and marks it extremely important as well as necessary to depend on them (Al-Jassim 2013; Abdul Khaliq et al. 2017a, b).

The aim of wastewater treatment plants is to reduce the solid particles available in the water, biodegradable organics, pathogenic bacteria and nutrients such as, phosphorus and nitrogen (Lindberg 2006; The World Bank Group 2016). Conventional wastewater treatment plants generally have different phases of treatment: primary, secondary and tertiary or advanced. Primary, also known as mechanical, removes solid particles from the sewage. Secondary, also known as biological, eliminates the organic matter that has bypassed the primary treatment, and the method is by using microorganisms that break down organic matter to carbon dioxide and water, in which those microorganisms salvage them to grow and reproduce. In addition, sludge process and tricking filters are few types of secondary treatment technologies. Tertiary treatment is the final step and is considered an additional phase, to remove the residual substances that are still found in the treated sewage by the primary and secondary treatments. The outcome effluent is considered "safe to be used" usually for agriculture use. Most wastewater treatment plants use chlorine as a disinfectant in the final step, but not all authorities agree on that (Lindberg 2006; The World Bank Group 2016; Waste Water Treatment Manuals 1997).

Although wastewater plants are not specifically planned to remove pharmaceuticals, these treatments can remove good amount of it, depending on the property of pharmaceuticals (chemical or physical) present in the particular wastewater. Most wastewater treatment plants have some type of biological treatment; this phase is involved in the removal of some amount of pharmaceuticals. Some other advanced methods including activated carbon, ozonation and advanced oxidation have shown to be better in the removal of pharmaceuticals than the biological treatment (WHO 2011).

In Oman, specifically at Al Ansab (Fig. 2), a wastewater treatment plant (operated by the Haya wastewater treatment company), the process is very similar to what is done around the world; they have primary, secondary and tertiary treatments for wastewater (Abdul Khaliq et al. 2017a). Figure 2 explains what is done at Al Ansab wastewater treatment plant (Haya wastewater 2016).

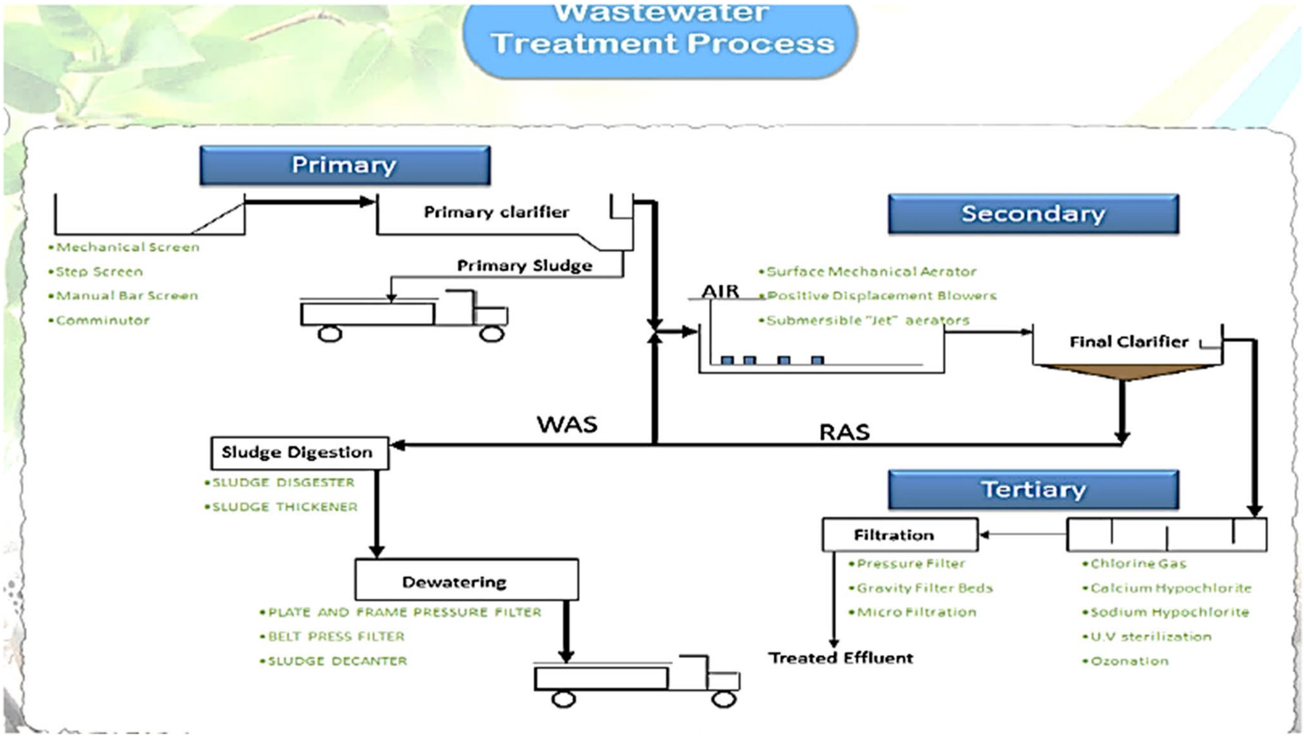

Fig. 2 Wastewater treatment process at Al Ansab, Muscat, Oman (Haya wastewater 2016)

Tests used to analyze wastewater for antibiotics

The occurrence of pharmaceuticals in general and antibiotics in specific in wastewater is very low in concentration as it becomes diluted (Mahmoud et al. 2013), making its analysis a challenge (Kasprzyk-Hordern et al. 2008). Therefore, a more accurate and an advanced measuring technology is needed (Kasprzyk-Hordern et al. 2008). Liquid chromatography with mass spectrometer was the most common analytical methods used to detect a wide range of environmental pollutants in water, including pharmaceuticals (Fatta et al. 2007; LEXI-COMP 2016a, b, c; Boeckel et al. 2015; Karthikeyan and Meyer 2006). In addition, a study developed a simple methodology with direct injection of the samples by HPLC with diode array detection (DAD); for a multi-residue analysis of five antibiotics of different classes (Teixeira et al. 2008), this method helps in fast screening for antibiotics.

Use of antibiotics in the World and Oman

Humans

There is evidence of rapid increase in antibiotics consumption between the years 2000 and 2010 around the world; the increase was seen to be 36%. Most of the increase was in developing countries. India was the largest consumer of antibiotics with 12.9×10^9 units (10·7 units per person), followed by China with $10{\cdot}0\times10^9$ units (7·5 units per person), then the USA with $6{\cdot}8\times10^9$ units (22·0 units per person) in 2010. Based on estimates reported most common antibiotics used globally, penicillin was used (2.5×10^{10} standard unit log), followed by cephalosporins (approx. 1.75×10^{10}), and followed by macrolides (approx. 0.85×10^{10}) and fluoroquinolones (approx. 0.75×10^{10}) (Boeckel et al. 2014).

The increase in antibiotics is definitely due to the improvement of healthcare services in the developing countries and growth of the population. But it could also be due to the overuse of antibiotics to self-limiting illnesses or used inappropriately. Unfortunately, among the enhanced consumption of antibiotics, is the increment of polymixin B throughout these years (Boeckel et al. 2014). Polymixin B is a bactericidal antibiotic, which causes leakage of the bacterial membrane leading to bacterial death (LEXI-COMP 2016a, b, c). Polymixin B is currently used as a last resort antibacterial and most commonly in antibiotic-resistant bacteria. The over use of polymixin B could mean that resistance has occurred and many antibiotics are not working (Boeckel et al. 2014).

In Oman, there are currently no published data on the amount of antibiotics used. At the Sultan Qaboos University Hospital (SQUH), the Pharmacy Department of Drugs information section has provided the most commonly used antibiotics in SQUH. Some of the reported antibiotics are: phenoxymethylpenicillin (penicillin), augmentin (penicillin), co-trimoxazole (combination of trimethoprim and sulfamethoxazole), cefuroxime (cephalosporin) and ciprofloxacin (fluoroquinolone). It is important to highlight that the list of consumed antibiotics in Oman shows a close association with the global trend in the use of antibiotics.

Animals

Antibiotics are also used in animals as well, up to double amount than humans for disease preventions and growth promotion. The demand on livestock worldwide has increased significantly over the years; therefore, producing countries have to maximize their production. One method is by giving antimicrobials to keep the animals in good health and maintain reproduction. There are studies that have shown that the use of antimicrobials on livestock is much higher than the human use. It is estimated that the annual use of antibiotics globally (antimicrobials per kilogram of animal produced) in cattle, chicken and pigs is 45 mg/Kg, 148 mg/Kg and 172 mg/Kg, respectively. According to Boeckel et al. (2015), an estimation of increment of antimicrobial use from the year 2010 to the year 2030 would be 67% (from 63,151 ± 1560 to 105,596 ± 3605 tons).

Unfortunately, the use of antimicrobials in animals is not regulated nor is it standardized in many countries, leading to overuse of antimicrobials, which eventually affects the environment (Boeckel et al. 2015). Just like the use of antibiotics in humans globally, the published data on antibiotics used in Oman are not available from the published sources.

Common antibiotics found in wastewater effluent in different countries and Oman

In different parts of Sweden, Lindberg (2006) did a study from the chemistry department of Umea University and reported that five different wastewater plants were studied for antibiotics in wastewater effluent. The study found that each plant had different antibiotics with different concentrations; the most common antibiotics were: fluoroquinolones, ofloxacin, ciprofloxacin, sulfamethoxazole, trimethoprim, and doxycycline. Further, it was reported that the usage and consumption of penicillins were the most consumed antibiotics in Sweden (Lindberg 2006).

Another study was conducted in Wisconsin, USA, and in this study seven wastewater treatment plant effluents were analyzed, the study found 6 different antibiotics in the effluent, different concentrations in different plants, and they were tetracycline (0.07–0.37 μg/L), trimethoprim (0.12–0.55 μg/L), sulfamethoxazole (0.05–0.37 μg/L), macrolides (approx. 0.3 μg/L), and fluoroquinolones in the form of ciprofloxacin (0.04–0.14 μg/L). Not surprisingly, concentrations of those antibiotics were higher in the influents in comparison with the effluents. It was also noticed that there were change in concentrations with respect to different seasons (Karthikeyan and Meyer 2006).

Watkinson et al. (2009) explained the situation in Australia on the presence of antibiotics in five wastewater treatment plant effluents that were investigated in Queensland. The study was undertaken for effluents in order to find out a complete list of all antimicrobials. This study found that there were concentrations of macrolides, fluoroquinolones and sulfonamides ranging from 0.01 to 14.5 μg/L. In comparison with the case of Sweden study, penicillin was the most consumed antibiotic in Australia, but minimum amount was found in the effluent. The overall extraction of antimicrobials comparing the influent with the effluent was about 80% by wastewater treatment plants.

A study in Hong Kong has demonstrated the existence of antibiotics in seven wastewater treatment plant effluents. The most common antibiotics found were fluoroquinolones (ofloxacin in the range of 96–7870 ng/L), norfloxacin (35–4000 ng/L), β-lactams (cefalexin in the range of 180–4000 ng/L), macrolides (erythromycin in the range of 250–4000 ng/L), sulfamethoxazole (5–300 ng/L) and trimethoprim (60–450 ng/L). This study observed that wastewater treatment plants that use different phases of treatments such as primary, secondary and tertiary have the capacity to increase the removal efficiency (Leung et al. 2012).

It was shown from the above countries that the most common antibiotics found in wastewater plants effluent were fluoroquinolones, sulfonamides, macrolides and trimethoprim (Lindberg 2006; Karthikeyan and Meyer 2006; Watkinson et al. 2009; Leung et al. 2012). Several studies from different countries surprisingly showed high consumption of penicillin but low or minimal concentrations in effluents (Lindberg 2006; Watkinson et al. 2009; Leung et al. 2012). This factor can relate to the consumption of the most common antibiotics found in wastewater plant effluents. But what is surprising that penicillin was the most commonly used at the global scale, but none of the wastewater plants in the above countries reported its occurrence (Michael et al. 2013; Jelić et al. 2012).

There are no published data specifically on wastewater effluent testing for antibiotics in Oman, but there are studies on multiple drug resistance bacteria, which could indicate on the presence of antibiotics as well. Mahmoud et al. (2013) found that in treated wastewater effluent, there were multiple antibiotic-resistant bacteria and the most common antibiotics they were resistant are ampicillin (83.3%) and carbenicillin (66.7%), and none to sulfamethoxazole. This study indicates that inappropriate use of antibiotics in humans and animals has enhanced the development of antibiotic-resistant bacteria strains which could adversely affect the environment. Another study done in Oman by Al-Bahry et al. (2012) has demonstrated the most common multiple antibiotic-resistant bacteria resistance to antibiotics mainly ampicillin (100%), sulfamethoxazole (approx. 95%), carbenicillin (80%), followed by streptomycin (approx. 77%) and the rest of antibiotics.

Reuse of wastewater effluent in Oman

Reuse of wastewater effluent in Oman is mainly due to lack of freshwater resources, the large quantity of wastewater effluent availability, cost reduction and conservation of the freshwater available for other uses (Baawain et al. 2014a, b, 2015). In addition, due to the rapid development in agriculture and industrial sections in Oman over the past four decades, there is an increase in the demand of water (Mahmoud et al. 2013; Abdul Khaliq et al. 2017a). Oman's main water sources are: conventional and non-conventional. Conventional includes groundwater, aflaj and springs, while non-conventional includes desalinized water and treated wastewater (Al-Khamisi 2014).

Table 1 provides the information on wastewater treatment plants that are available in Oman, the treated effluent (TE) produced from each plant (m^3/d) and their main applications (Baawain et al. 2014a). Although the main reuse of wastewater effluent in Oman is for landscape (Baawain et al. 2014b), agriculture is another application for treated effluent, due to the high demand of food and the development of agricultural areas; thus, freshwater or natural source of water is not enough. As per Al-Khamisi and Ahmed (2014), the amount of toxic or harmful pollutants tested on plants using treated effluent was found to be below the recommended safe limit standards.

A considerable amount of research has been performed in Oman on various issues related to wastewater. Wastewater research focused on growing crops, impacts on soil, aquifer recharge using treated wastewater and other relevant issues (Al-Khamisi et al. 2016a, b; Al-Busaidi and Ahmed 2014; Abdel Rahman et al. 2011; Abdul Khaliq et al. 2017a; Al-Farsi et al. 2018), whereas sludge produced as by-product of wastewater treatment was investigated for its quality and likely use in crop production and remediation of contaminated sites (Al-Busaidi et al. 2015; Padmavathiamma et al. 2014; Al-Busaidi 2014).

Table 1 Wastewater treatment plants in Oman. *Source*: Baawain et al. (2014a)

Wastewater treatment plants (WWTPs)	TE (m^3/d)	Sludge (Ton/d)	Main TE application
Al-Ansab	21,000	66	Landscaping
Darsait	18,000	33	Landscaping
Rusayl Ind	800	(~2)	Landscaping
Rusayl Dom	285	(~0.7)	Landscaping
Salalah STP	20,000	35.5	Recharge Wells
Salalah Ponds	1500	(~3)	Wadi Overflow
Raysut Ind.	150	(~0.4)	Landscaping
Sohar STP	6600	(~15)	Landscaping
Sohar Ind.	300	(~0.8)	Landscaping

The World Health Organization (WHO) has set three different methodologies to establish guidelines for reuse of wastewater effluent in agriculture. First, "the absence of fecal indicator organisms in wastewater, there should be no indication of any fecal coliform in the treated wastewater effluent for it to be used for irrigation of crops"; Second, "the absence of a measurable excess of cases of enteric disease in the exposed population"; using epidemiological studies is to confirm no actual risk of infection of reusing treated wastewater effluent, and third "model-generated estimated risk below a defined acceptable risk"; estimation of an annual risk could be done by a quantitative microbial risk assessment (QMRA) model. Table 2 provides revised recommendations for reuse of treated wastewater in agriculture.

The risk on humans and risk management

The reuse of treated wastewater effluent for irrigation is a common practice in many countries; it is certain that the reuse of treated wastewater effluent contaminated with multiple antibiotic-resistant bacteria would also reach the watered crop; this could harm the end user of these vegetables or fruits (Al-Bahry et al. 2009; Al-Farsi et al. 2018). The use of treated wastewater effluent as a reuse in agriculture and crop growing has shown to reach the crops through root uptake. A study by Wu et al. (2012) has found that spinach and lettuce are the most vegetables that uptake pharmaceuticals and personal care products from reusing treated wastewater effluents used in the irrigation. From the pharmaceuticals detected, trimethoprim is the only antibiotic which had an uptake with detected concentrations of $1.1 \pm (0.2–0.4)$ (ng/G dry weight) in both lettuce and spinach, while sulfamethoxazole was detected but lower than the method detection limit. It is of a concern specifically in vegetables or fruits that are eaten raw or uncooked (Wu et al. 2012).

Livestock products that are polluted by antibiotics could result in harmful effects to the humans such as allergic reactions or anaphylaxis, and disturbing the microflora residing in the gastrointestinal tract. A proper withdrawal time should be kept before slaughtering the animal, to avoid having those pollutants in meat. This is also another mechanism in which resistance could occur (Kadim 2014). Kümmerer (2008) has studied antibiotics in wastewater extensively and has seen

Table 2 Wastewater discharge and reuse standards A and B, Oman Source: MECA MD145/93

#	Specification	(Class A)	(Class B)
1	Crops	Vegetables likely to be eaten raw. Fruit likely to be eaten raw and within 2 weeks of any irrigation	Vegetables to be cooked or processed Fruit if no irrigation within 2 weeks of cropping Fodder, cereal and seed crops
2	Grass and ornamental areas	Public parks, hotel lawns recreational areas. Areas with public access Lakes with public contact (except place which may be used for praying and hand washing)	Pastures Areas with no public access
3	Aquifer recharge	All controlled aquifer recharge	
4	Method of irrigation	Spray or any other method of aerial irrigation not permitted in areas with public access unless with timing control	
5	Any other reuse applications	Subject to the approval; of the Ministry	

that the amount of antibiotics eventually reaches the environment which is in the range of ng/L to µg/L, which is thought to be negligible, but little is known about the fate of metabolites and how it affects humans. The low dose and long-term effect of medications or antibiotics in wastewater eventually reused in agriculture and reaching of human by consumption is also not known. The consequence on babies, fetuses and elderly should also be considered and studied (Kümmerer 2008). The occurrence of sub-therapeutic doses of antibiotics on bacteria over a prolonged period leads to resistance, which is a threat to the environment (Al-Bahry et al. 2009).

Little is known of the risks associated with effluents containing trace pollutants of antibiotics, although research in this area is developing. Oetken et al. (2005) demonstrated that the antiepileptic carbamazepine had a significant and specific chronic effect against the oligochaete chironomus at environmentally relevant concentrations. This is further highlighted by Flaherty and Dodson (2005) who observed chronic fluoxetine exposure at low concentration significantly increased the daphnia fecundity. Furthermore, a mixture of fluoxetine and clofibric acid caused significant mortality, and deformities and mixtures of three-to-five antibiotics elicited changes in daphnia sex ratio (Flaherty and Dodson 2005).

The research to date on human and animal exposures to pharmaceuticals and personal care products (PPCPs) has linked them to an array of carcinogenic, mutagenic and reproductive toxicity risks (Khan and Nicell 2015; Vasquez et al. 2015; Al-Farsi et al. 2017). A number of PPCPs act as endocrine disruptors, which interfere with the functions of hormonal systems in both humans and animals (Catanese et al. 2016; Kiyama and Wada-Kiyama 2015; Al-Farsi et al. 2017). Associations have been identified between endocrine disruptors and recent trends of increased incidences of breast and prostate cancers (Rochester 2013). Reproductive disorders have been found to occur following prenatal exposure to compounds such as diethylstilbestrol (Maeda et al. 2014; Wise et al. 2016; Al-Farsi et al. 2017).

A comprehensive review of the acute and chronic toxicities of PPCP compounds in aquatic organisms has been conducted (Brausch et al. 2012; Al-Farsi et al. 2017). Of the compounds investigated, dextropropoxyphene, sertraline, thioridazine and diphenhydramine were highlighted as having the greatest potential for acute toxicity to the studied algal, vertebrate and fish populations. Bacteria, fish and amphibians were found to be relatively insensitive to the acute toxicity of analgesic drugs, while phytoplankton and invertebrates were the most sensitive to the acute toxicity of these compounds.

Plant uptake of pharmaceuticals, which occurs when treated wastewater is reused for irrigation, may also affect plant development. It is, in part, unclear whether the negative effects on plants originate from direct damage to the plant by the pharmaceuticals themselves or whether the antimicrobial action of pharmaceuticals on soil microorganisms is responsible for the damage by affecting the plant–microorganism symbiosis. The latter is attributed to the fact that antibiotics in the soil may affect plant development indirectly by disrupting soil communities: The decrease in the number of soil bacteria leads to a lack of food for soil fauna (protozoa, nematodes, micro-arthropods) and finally affects soil function: Plant residues are decomposed more slowly, denitrification is slower, and therefore, nutrients are recycled more slowly. Degradation productions of these chemicals can also be considered as contaminants contributing to these complex mixtures that are present (Al-Farsi et al. 2017). There is even some evidence that these degradation products can be as active or toxic as their original compound (Halling-Sorensen et al. 2002; Sengeløv et al. 2003).

There is a poor understanding of the risks and effects that the pharmaceuticals and their metabolites implications. Some thoughts of the management to reduce risk are returning medications to pharmacies program, to avoid the flushing of unused medications. Another method is to have advanced effluent treatment plants, to minimize the amount of pharmaceuticals in the wastewater. In addition, prescribing awareness should be done such as the overuse of antibiotics in viral infections (Kümmerer 2008). Green and sustainable pharmacy could be one of the best options to solve the risk associated with pharmaceuticals. According to the principles of green chemistry (Anastas and Warner 1998), the functionality of a chemical should include the properties of a chemical necessary not only for its application, but also for its fast and easy degradability after its use. Taking into account the full life cycle of chemicals will lead to a different understanding of the functionality necessary for a chemical. In the present discussion, improvement of synthesis and renewable feedstock are very prominent, whereas the environmental properties of the molecules have been discussed less. Applying these principles and the knowledge of green chemistry to pharmaceuticals is necessary in the future.

Research needs assessment

The current state of antibiotics in wastewater research in Oman is giving its first steps. The main reason behind this is lack of laboratory facilities that are capable of measuring antibiotics at low concentrations. Trained manpower to carry out such laboratory measurements is also lacking. The first step in building a viable and sustainable research on this topic will require capacity building. Once such facilities and trained manpower are available, research should continue on finding out what antibiotics are present in wastewater at various stages of treatment, efficiency of various treatment systems (activated sludge, membrane bioreactor, constructed wetlands, adsorptions) to remove such pollutants and its persistence in treated wastewater, uptake by plants when irrigated with treated wastewater, accumulation in soils, movement to groundwater aquifers. Specific considerations should be given to prepare guidelines for the use of treated wastewater containing antibiotics for various purposes and develop appropriate standards based on research findings.

Conclusion and recommendations

Antibiotics have been found in treated wastewater effluent in different countries including Oman, and it was evident that more the treatment plant goes with subsequent stages of treatment, the less the amount of antibiotics occurred in the effluent. Resistance genes against various antibiotics have been isolated from the wastewater treatment systems and final effluents in the Sultanate of Oman. However, there are research and data gap on antibiotics in Oman; hence, more research is required, especially to study the effluents and its analysis for the concentration of antibiotics. In addition, this review also suggests investigating more advanced technologies, such as photo-catalysis and nanotechnology in wastewater treatment plants to get rid of antibiotics, which can eventually harm the environment, humans and animals. Further, development of guidelines is crucial in amounts of antibiotics acceptably occurring in treated wastewater effluent and if they could be suitable for agriculture without causing any harm.

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