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Novel Approaches to Monitoring and Remediation of Veterinary Antibiotics in Soil and Water: A Review

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Abstract: A vast increase of antibiotics usage in concentrated animal feeding operations (CAFOs) over the last few decades has led to an environmental risk due to the presence of antibiotic residuals in different environmental compartments. Especially in Korea, the use of antibiotics in CAFOs is much greater than in other developed countries. One of the primary adverse impacts of antibiotic residuals in the environment is that they readily produce antibiotic resistant bacteria (ARB), which exert detrimental effects on the ecosystem as well as human health. In this article, the impacts of veterinary antibiotic residuals with regard to their quantification and management, and desirable remediation technologies have been widely reviewed. This review article concluded that the continuous monitoring should be required to ensure the safety of antibiotic residuals in the surrounding environments. Furthermore, the management guidelines of antibiotic residuals need to be developed in the future.

Key Words: Antibiotic quantification, Remediation, Veterinary antibiotics

Introduction

Since their discovery in 1928, antibiotics have rapidly changed the world because of their incredible capability to cure many life-threatening diseases (Strohl, 2000; Cars *et al*., 2008). Antibiotics have been intensively used as CAFOs for several decades to control disease and improve animal growth (McEwen, 2006; Bradford *et al*., 2008). Antibiotics, which are classified as active pharmaceutical ingredients (APIs), consist semi-synthetic or synthetic molecules with the ionic nature that have antimicrobial activity and are applied parentally, orally or topically (Kemper, 2008; Kümmerer, 2008). However, only 10-20% of the antibiotics applied to animals are likely to be utilized, while the rest are excreted through the urine or feces (Connor, 2004) which is being released into the environment (Montforts *et al*., 1999; Tolls, 2001; Winckler and Grafe, 2001; Boxall *et al*., 2002; Halling-Sorensen *et al*., 2002; Aga et al., 2003; Vaclavik *et al*., 2004). Furthermore, antibiotic resistance of bacteria becomes problematic when it leads to therapeutic failure or the need to overuse more toxic drugs because of increasing frequency, duration or severity of infection (Barza, 2002).

The use of antibiotics can threaten ground water, drinking water and soil due to their potential toxicity (Heim *et al*., 2004). Consequently, the abuse of antibiotics may lead to the development of antibiotic resistance genes (ARG) via natural selection (Cars *et al*., 2008). Studies have found that ARG can be produced and may be present in the sediments of the mixed-landscape rivers (Pei *et al*., 2006) and activated sludge wastewater treatment plants (Auerbach *et al*., 2007). Chee-Sanford *et al*. (2001) also found tetracycline resistance genes in lagoons and groundwater located in the vicinity of two swine production facilities in

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the United States. Groundwater or soil can also serve as a reservoir for ARG distribution. Moreover, ARG have been detected in agricultural soils treated with pig manure slurry (Sengelov *et al*., 2003), as well as in wastewater, surface water and drinking water biofilms (Schwartz *et al*., 2003). Auerbach *et al*. (2007) found a wide variety of tetracycline resistance genes in all samples collected from different wastewater treatment plants in the United States.

Another problem associated with antibiotics released into the environment is their side effects and modes of action in humans and animals (Fent *et al*., 2006). Many studies found greater antibiotic occurrence than anticipated through evaluation of the susceptibility of enteric *E. coli* to antibiotics (Pena *et al*., 2004). Different strains of *E. coli* isolated from animal feces have been found to be resistant to amoxicillin, tetracyclines and sulphonamides (Pena *et al*., 2004). They also revealed that a high proportion of *E. coli* in fecal samples was detected to be resistant to sulphonamides and tetracyclines (88% and 85%, respectively).

The presence of antibiotics in agricultural soil causes deleterious impacts on human health due to its uptake by plants. It was recently suggested that these compounds are translocated by plants and exert a toxic effect on plant growth. The uptake of oxytetracycline by alfalfa inhibited the growth of shoot and root by 61% and 85%, respectively (Kong *et al*., 2007). Liu *et al*. (2009) studied the phytotoxic effect of six antibiotics on plant growth and soil quality for rice, cucumber and sweet oat crop plants, and found that rice was most sensitive to sulfamethoxazole, with an EC_{10} value of 0.1 mg/L. They also found that sulfamethoxazole and sulfamethazine greatly inhibited soil respiration and phosphate activities, whereas chlortetracycline, tetracycline and tylosin had little effects.

Veterinary antibiotics may have a higher risk to the environment than human pharmaceuticals via direct release into different ecosystems and can be exposed to the agricultural soil via animal manure applications (Park, 2006). In Korea, some antibiotics such as chlortetracycline, oxytetracycline, sulfamethazine, sulfathiazole and tylosin have been identified as having the greatest priority during environmental risk assessment (ERA) (Seo *et al*., 2007). However, there is little information available regarding their toxicity or the effect of long-term exposure to low concentrations of antibiotics on environmental health, even though numerous studies have been conducted to evaluate residual antibiotics (Daughton and Ternes, 1999; Boxall *et al*., 2004). This review article was prepared i) to emphasize the importance of monitoring residual antibiotics in soil and water as one of the critical issues for environmental safety, ii) to identify emerging technologies for reducing their environmental risks and iii) to discuss future directions and scenarios for monitoring and remediation of antibiotics.

Use of Veterinary Antibiotics

Antibiotics are widely used as therapeutic agents to control infectious animal diseases and promote animal growth in CAFOs. The antibiotics most commonly added to feed provided to cattle, pigs, poultry, pets and fish are tetracyclines, sulfonamides and macrolides (Ha *et al*., 2003; Kim and Carlson, 2007; Kong *et al*., 2007). Table 1 shows veterinary antibiotics registered and used as growth promoters in Korea and other countries (National Research Council, 1999; Mellon *et al*., 2001; Samarh *et al*., 2006). Wise *et al*. (1998) reported that approximately 50% of all produced antibiotics are used in animal husbandry and 20% of those are employed for therapeutic use, while 80% are utilized for prophylactic/growth promotion. In addition, about half of the antibiotics produced in the United States are used for agriculture as growth promoters (Levy, 1998; Dewey *et al*., 1999). In Europe, the average amount of antibiotics used in 1996 and 1999 was ~11,750 tons, of which ~42% was used in animal feeding operations (AFOs). Moreover, the most intensively used veterinary antibiotics are a group of tetracycline including chlorotetracycline, oxytetracycline, doxycycline and tetracycline, and a group of sulfonamide including sulfanilamide, sulfadiazine, sulfadimidine, sulfadimethoxine, sulfapyridine and sulfamethoxazole (Thiele-Bruhn, 2003; Bradford *et al*., 2008)

As shown in Table 2, the amount of antibiotics used in Korea in 2004 varied depending on an antibiotic groups. Specifically, the amounts of antibiotics used were as follows (% of the total amount of antibiotics used): tetracyclines (51%), penicillins (13%), sulfonamides (12%), aminoglycosides (4.6%), macrolides (3.6%), quinolones (3.3%), polypeptides (2.3%) and chloramphenicols (1.5%) (Seo *et al*., 2007). The amount of antibiotics sold in Korea slightly decreased by 1,667, 1,670, 1,515 and 1,400 tons in 2001, 2002, 2003 and 2004, respectively. The overall usage in 2001, 2002 and 2003 occurred in the following order: tetracyclines, sulfonamides, penicillins,

Table 1. Veterinary antibiotics registered as growth promoters in Korea and other countries

Country	Antibiotic group	Usage	Reference
Korea	Tetracyclines Sulfonamides Penicillins Aminoglycosides Macrolide Polypeptides	Swine, Cattle, Poultry	Ha *et al*. (2003), National Veterinary Research and Quarantine Services (2005), Seo *et al*. (2007)
USA	Tetracyclines Macrolides Ionophores Penicillins	Cattle, Swine, Poultry Chicken, Turkey, Cattle, Swine Cattle Poultry	Sarmah *et al*. (2006), Mellon *et al*. (2001)
Canada	Macrolides Tetracyclines Sulfonamides Ionophores	Breeder, Broilers, Sheep Chicken (breeder, layer), Turkey, Swine, Cattle, Sheep Swine, Cattle Swine, Cattle	Health Canada (2002), Sarmah *et al*. (2006)
European Union (EU)	Macrolides Polyethers (ionophores)	Turkeys, Chickens, Calves, Lambs and Pigs Pigs, Cattle (fattening)	Sarmah *et al*. (2006)
Australia	Macrolides, Polyethers (ionophores) Polypeptides	Pigs, Cattle Pigs, Cattle Meat, Poultry	Sarmah *et al*. (2006)

Table 2. Consumption of veterinary antibiotics in Korea in 2004 (National Veterinary Research and Quarantine Services, 2005)

Chemical group	Number of active ingredients	Consumption	Proportion
		kg	%
Tetracyclines	4	698,632	51.1
Penicillins	5	169,166	13.3
Sulfonamides	17	162,241	11.9
Aminoglycosides	8	62,829	4.6
Macrolide	8	48,587	3.6
Quinolone	11	44,509	3.3
Polypeptides	5	31,796	2.3
Chloramphenicols	3	20,351	1.5
Lincosamides	2	11,981	0.9
Cephaloporins	4	1,865	0.1
Miscellaneous	16	116,078	8.5
Total	83	1,368,011	100.0

nitrofurans, aminoglycosides, macrolides, quinolones and polypeptides (Ha *et al*., 2003; Korea Food and Drug Administration, 2006).

Ha *et al*. (2003) surveyed the antimicrobial agents in three regions using the evaluation program of their use in feed additives, export, hospitals and other applications in Korea since 2001. They found that the greatest volume of antibiotics sold was administered to pigs, followed by poultry, fish and cattle. Additionally, they found that 10 of the 83 veterinary antibiotics identified were administered at a high dose (more than 25 Mg) in Korea. Indeed, the use of veterinary

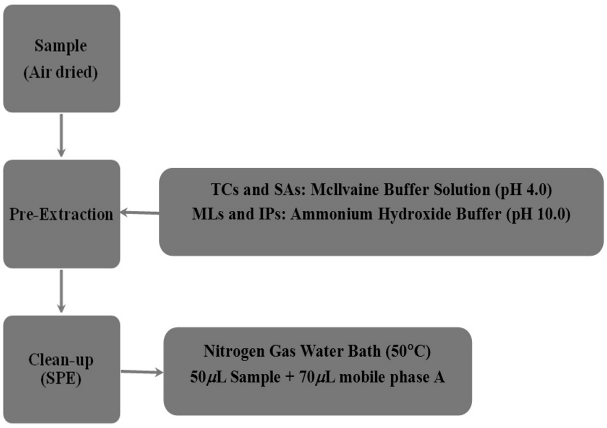

Fig. 1. Schematic diagram of sediment sample preparation for antibiotics determination (Kim and Carlson, 2007).

antibiotics in Korea was higher than in many other developed countries (Kim *et al*., 2008). For example, the amount of antibiotics used in Korea was 15 times greater than the amount used in Sweden in 2003 and two times greater than the amount used in the UK in 2004, while it was one and a half times and 16 times greater than the amounts used in Japan and Denmark, respectively, in 2005 (National Veterinary Research & Quarantine Service, 2005; Veterinary Medicines Directorate, 2005; Johansson and Mollby, 2006).

Methodology to Quantify Veterinary Residual Antibiotics

Extractions of antibiotics from both aqueous and solid phases are generally complicated (Boxall *et al*., 2003; Christian *et al*., 2003). Chemistry-based techniques for the extraction of antibiotics were first described by Fedeniuk and Shand (1998), who noted that there are two methods for the separation of antibiotics, liquid-liquid partitioning and solid-phase extraction. In addition, schematic diagram for the preparation of tetracyclines, sulfonamides and trimethoprim in both aqueous and solid phases using a liquid chromatography mass spectrometry (LC-MS/MS) is presented in Fig. 1.

Liquid-liquid partitioning

Liquid-liquid extraction (LLE) protocols are used to extract antibiotics from aqueous matrices by partitioning the antibiotic between immiscible phases and then extracting the drug from one phase to another. To isolate the antibiotics, the supplementary extraction must be done. Desorption of antibiotics from the matrix is based on hydrogen bonding, and dipole-dipole and covalent interactions (Florence and Attwood, 1981). Detailed procedures and principles have been described by Soto *et al*. (2005).

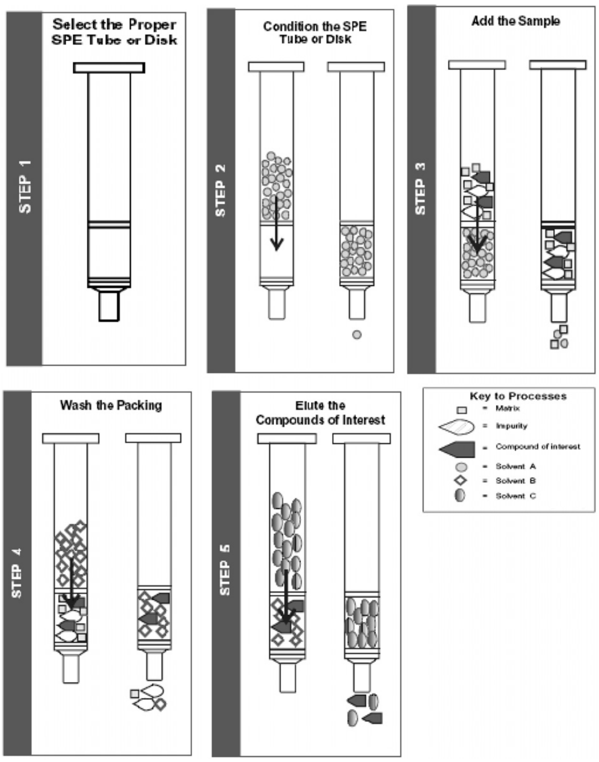

Fig. 2. Solid phase extraction (SPE) procedures for antibiotics determination (Kim and Carlson, 2007).

Solid-phase extraction (SPE)

Solid-phase extraction (SPE) has recently replaced the LLE method because of its advantages such as the needs for smaller sample size and higher reproducibility. SPE is also faster than LLE and can avoid the creation of an emulsion. Moreover, SPE offers decreased dependence on the use of chlorinated hydrocarbons, which is considered a desirable environmental benefit. As shown in Fig. 2, there are four basic procedures involved in generating a proper SPE sorbent: i) the sorbent bed must undergo proper chemical conditioning to enable reproducible retention, ii) the sample must be added to the sorbent (cartridge) to allow selective retention of the analyte and removal of other materials, iii) the packing must be washed with an extraction solvent to remove impurities and iv) the remaining substances must be eluted using an adequate solvent to extract the antibiotics (Kim and

Table 3. LC/ MS operating conditions for antibiotic quantification (Kim and Carlson 2005; 2007)

LC-MS parameters	ERFX and CPFX	TCs, SAs and TMP
Column	Luna (Phenomenex)	Luna (Phenomenex)
	150 mm x 3 mm C8, 5 μm	150 mm x 2 mm C8, 5 μm
Guard column	Univ. Sec. Guard (Phenomenex)	Univ. Sec. Guard (Phenomenex)
	4 mm x 2 mm C8U	4 mm x 2 mm C8U
Flow	0.25 mL/min	0.25 mL/min
Component A	H_2O 0.01% HCOOH	H_2O
Component B	ACN 0.01% HCOOH	ACN
Component C		0.5% HCOOH 10 mM NH_4OAc
Solvent program	10% B, 90% A for 2 min	5% B, 90% A, 5% C for 0.5 min
	60% B, 40% A in 2 min	20% B, 75% B, 5% C in 6.5 min
	60% B, 40% A for 2 min	50% B, 45% B, 5% C in 3 min
	10% B, 90% A in 3 min	95% B, 5% C in 2.1 min
		95% B, 5% C for 0.9 min
		5% B, 90% A, 5% C in 0.1 min
MS method	MS	MS-MS
MS mode	ESI-PI	ESI-PI
Capillary voltage	3000 V	3500 V
Source temperature	120℃	120℃
Desolvation temperature	250℃	250℃
Cone gas flow	50 L/h	90 L/h
Desolvation gas flow	500 L/h	500 L/h
Multiplier voltage	650 V	650 V

Carlson, 2007). A more detailed description of this process can be found in articles previously published by Kim and Carlson (2005; 2007). Table 3 illustrates the operating conditions of LC and MS for the analysis of antibiotics such as tetracyclines and sulfonamides.

Residual Antibiotics in the Environment

Concentrations of antibiotics in swine, poultry, dairy and beef lagoon water samples have been found to range from <0.01 to 1,340 μg/L and they have been detected in rivers, lakes and reservoirs worldwide (Lin *et al.*, 2006; Kim *et al.*, 2007; Bradford *et al.*, 2008). Antibiotics are widely disseminated in the environment via the sewage treatment. Recent studies have been conducted to evaluate the potential impacts of antibiotics on ecosystem health, but most of these studies have been limited within North America and Europe (Kolpin *et al.*, 2002; Hilton and Thomas, 2003; Fent *et al.*, 2006). Kolpin *et al.* (2002) reported that the detectable level of antibiotics was present in 48% of the United States Geological Survey (USGS) samples in the United States.

The present knowledge regarding the toxicity of antibiotic metabolites or the degradation in addition to the occurrence of long-term exposure to low doses or abuse of antibiotics and their impacts on the environment is also very limited (Boxall *et al.*, 2004). Antibiotics are commonly presented in animal urine and feces due to their low absorption rates, therefore, these antibiotics and their metabolites often show up in manure (Halling-Sorensen *et al.*, 2002; Aga *et al.*, 2003; Vaclavik *et al.*, 2004). Veterinary antibiotics can also enter the environment through landfill and manure application, after which they are transported to surface water, sediments and finally groundwater (Fig. 3). Overall, the pathways of veterinary antibiotics released into the environment vary based on waste storage capacity, manure application practices and the type of antibiotics used.

Occurrence of antibiotics in water

Long term exposure to antibiotics can be harmful to aquatic and terrestrial organisms (Klavarioti *et al.*, 2009). Despite this risk, the detrimental level of anti-

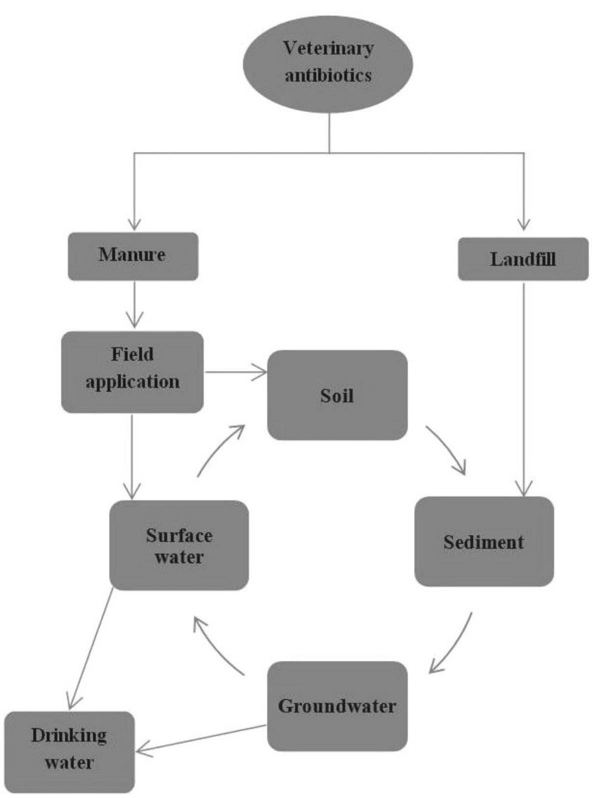

Fig. 3. Anticipated pathway of antibiotics provided to livestock.

biotics such as ciprofloxacin (between 0.7 and 124.5 μg/L) and ampicillin (between 20 and 80 μg/L) have been detected from hospital effluent (Hartmann *et al.*, 1999; Kümmerer, 2001).

Antibiotics used as drugs have been detected in rivers, lakes and reservoirs worldwide (Golet *et al.*, 2002; Kolpin *et al.*, 2002; Gross *et al.*, 2004; Lin *et al.*, 2006; Kim *et al.*, 2007). Wastewater is contaminated with a high level of antibiotics that are intensively used in CAFOs as therapeutic and growth promoters (Bradford *et al.*, 2008). Additionally, the concentrations of oxytetracycline, tetracycline and sulfamethoxazole have been found to range from 0.07-0.15, 0.06-0.16 and 0.03-0.16 μg/L, respectively, in water samples collected along the Cache la Poudre River in Northern Colorado, the United States (Carlson *et al.*, 2004). Bradford *et al.* (2008) also found that the concentrations of antimicrobial agents in swine, poultry, dairy and beef lagoon water samples ranged from 0.01 to 1,340 μg/L. Furthermore, various types of antibiotics such as sulfamethoxazole, caffeine, acetaminophen, ibuprofen, cephalexin, ofloxacin and diclofenac were detected at average concentrations of 0.2, 0.39, 0.02, 0.41, 0.15, 0.14 and 0.083 μg/L, respectively, in > 91% of Taiwanese water samples from 23 sites (Lin *et al.*, 2008).

Occurrence of antibiotics in soil

The European Agency has restricted the concentration at < 0.1 mg/kg of residual veterinary antibiotics in soils (European Medicines Agency, 1998). Nevertheless, the applications of animal manure and reused wastewater to agricultural fields are the main sources of residual antibiotics in soil ecosystems. For example, the concentrations of tetracycline as high as 86.2 μg/kg for 0-10 cm deep soil and 198.7 μg/kg for 10-20 cm deep soil were detected after repeated fertilization of 30-40 m^3 liquid manure (Hamscher *et al.*, 2002). Although antibiotics are partially degraded by physical, chemical and biological reactions in animal manure and soil, or their mixture, the half-life of chlortetracycline in manure is longer than 30 days (Montforts *et al.*, 1999). Degradation rate of antibiotics is affected by their characteristics including their solubility in water, as well as by environmental factors. Kim (2006) found that the concentrations of antibiotics in manure, such as chlortetracycline, tylosin and monensin, gradually decreased within 10 days when composting. Gavalchin and Katz (1994) found that the concentrations of chlortetracycline and tylosin in soil generally decrease by 56% at 40℃ and 60% at 4℃ after 30 days composting. These findings can be applicable to minimize the potential for the release of chlortetracycline, tylosin and monensin prior to the application of manure as a fertilizer.

Occurrence of antibiotics in Korea

Few studies have been conducted on the monitoring of residual antibiotics in soil and water in Korea (Han *et al.*, 2006; Park, 2006; Choi *et al.*, 2008). Choi *et al.* (2008) studied the presence of antibiotics in water samples collected from the Han River during three different seasons to determine if their concentrations varied seasonally and under different flow conditions. They found that the injurious levels of antibiotics, including acetaminophen (27,089 ng/L), caffeine (23,664 ng/L), cimetidine (8,045 ng/L) and sulfamethoxazole (523 ng/L), in the influents from the four sewage treatment plants. These detected amounts of each antibiotic were well correlated with the total volume of antibiotics used in Korea (Choi *et al.*, 2008). Lim *et al.* (2009) revealed that the concentrations of tetracycline, chlortetracycline, oxytetracycline, sulfamethazine, sulfamethoxazole, sulfamethoxazole and sulfathiazole ranged from below the detection limit (BDL) to 0.71 μg/L in surface water, from BDL to 27.61 μg/kg in sediment and from 0.12 to 157.33 μg/kg in soil at locations adjacent to the cattle manure composting facility in Korea.

Remediation of Antibiotics

Antibiotic resistance induces the environmental risk due to residual antibiotics released into the ecosystems. For agricultural soils, the removal of APIs should be needed to ensure environmental safety when wastewater or manure is applied. However, conventional remediation methods for APIs in wastewater have limited applicability because of difficulty in chemical or biological oxidation of APIs (Laridi, 2005).

Physicochemical treatment

In the last few decades, it has become clear that the conventional methods for the APIs remediation are costly. Therefore, several low-cost effective methods for APIs remediation are being developed. For example, Laridi *et al*. (2005) researched the application of different concentrations of $FeCl_3$ as a chemical coagulant in conjunction with both monopolar and dipolar electrode systems for the electrochemical treatment of liquid swine manure contaminated with antibiotics. They found that the electrochemical treatment using the Fe-MP (mild steel monopolar) of swine wastewaters contained high amounts of antibiotics was economically and practically beneficial relative to the chemical treatment using $FeCl_3$ as a coagulating agent. Petrović *et al*. (2003) investigated the removal efficiency of antibiotics using a standard wastewater treatment plant (WWTP) and suggested that advanced technologies such as membrane processes and advanced oxidation processes (AOPs) should be needed for higher efficiency (Klavarioti *et al*., 2009). As one of advanced technologies to remediate residual antibiotics from the ecosystems, the treatment with biological (MBRs) or non-biological membranes (reverse osmosis, ultrafiltration, nanofiltration) is considerable.

Advanced oxidation processes generally utilize ozone and other oxidation agents (UV radiation, hydrogen peroxide and TiO_2) to increase the degradation of antibiotics (Li *et al*., 2008). For example, Ternes *et al*. (2003) used 10-15 mg/L ozone as a tool to completely remove five antibiotics of trimethoprim, sulfamethoxazole, clarithromcin, erythromycin and roxithromycin, at concentrations of 0.34-0.63 μg/L. Additionally, paracetamol can be removed by ozonation and H_2O_2 photolysis (Andreozzi *et al*., 2003). Andreozzi *et al*. (2003) and Lopez *et al*. (2003) also studied the effectiveness and the feasibility of UV and UV/H_2O_2 processes for the removal of two pharmaceutical intermediates from water. They found that UV/H_2O_2 treatment led to the degradation of two pharmaceutical intermediates (5-methyl-1,3,4-thiadiazole-2-methylthio [MMTD-Me] and 5-methyl-1,3,4-thiadiazole-2-thiol [MMTD]). Moreover, ozone-based AOPs (O_3/H_2O_2 and O_3/UV) have been found to lead to increase oxidation efficiency. Polubesova *et al*. (2006) studied the removal of tetracycline and sulfonamide from water using a micelle-clay system (pre-adsorbed on montmorillonite) and found that it removed 96-99.9% of the antibiotics from water containing 5-50 mg/L sulfonamide in a batch experiment. Zwiener *et al*. (2000) also noted that the concentration of ozone used must be equal to the level of dissolved organic carbon (DOC) to ensure sufficient degradation of antibiotics.

The micro-scale and nano-scale iron particles remove residual antibiotics via three mechanisms: i) rapid reduction (rupture) of the β-lactam ring, ii) adsorption onto iron particles and iii) sequestration of the antibiotics in a matrix of precipitating iron hydroxides (Ghauch *et al*., 2009). However, nano-remediation of antibiotics is too expensive to be practical.

Bioremediation

Bioremediation is an emerging way for the degradation, extraction and stabilization of residual antibiotics at contaminated sites. Plant growth-promoting rhizobacteria (PGPR) in association with plants is commonly used to remediate soil contaminated with organic pollutants (Zhuang *et al*., 2007). Microorganisms may degrade and mineralize organic compounds in association with plants (Saleh, 2004). Lee *et al*. (2009) evaluated technologies available for the degradation of residual antibiotics in soil and water environments that adopted composting, anaerobic digestion and adsorption. Several methods have also been developed to improve the degradation efficiency and the tolerance of bacteria to organic contaminants in soils.

Phytoremediation

Phytoremediation can be utilized for *in situ* remediation of drug contaminated water and soil. Table 4 summarizes different plant species that can absorb antibiotics into

Table 4. Plant Species Having The Ability To Accumulate Antibiotics In Their Tissues

Plant Species	Antibiotic Group	Reference
Allium Cepa L.	Chlortetracycline	Kumar *Et Al*. (2005)
Brassica Oleracea L. Capitata Group	Chlortetracycline	Kumar *Et Al*. (2005)
Zea Mays L.	Chlortetracycline	Kumar *Et Al*. (2005)
Azolla Filiculoides L.	Sulphadimethoxine	Forni *Et Al*. (2002)
Myriophyllum Aquaticum	Oxytetracycline /Tracycline	Gujarathi *Et Al*. (2005)
Helianthus Annuus L.	Xenobiotics (Benzotriazoles)	Castro *Et Al*. (2004)

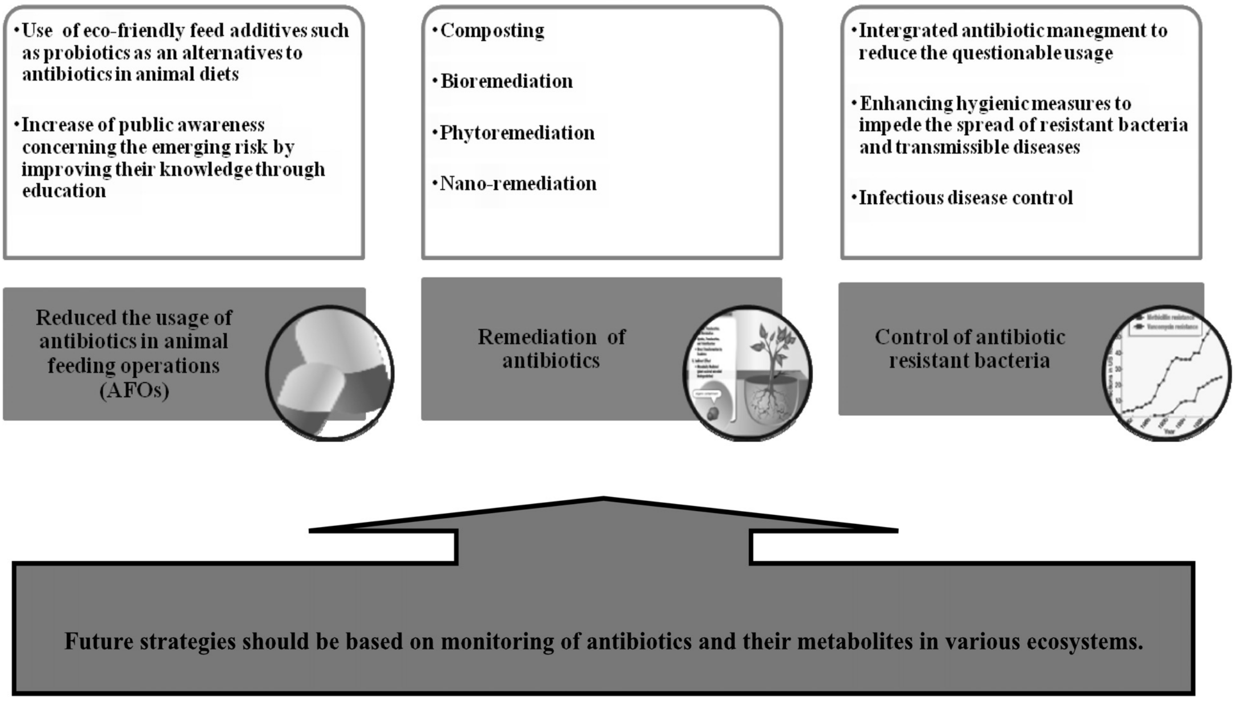

Fig. 4. Schematic Diagram Showing The Scenarios Recommended For Controlling The Risk Associated With Residual Antibiotics In Different Environments.

their tissues. Corn (*Zea mays* L.), green onion (*Allium cepa* L.) and cabbage (*Brassica oleracea* L. Capitata group) plants grown in manure contained antibiotics have been shown to absorb chlortetracycline at levels of 2-17 ng/g fresh weight, with the accumulation of chlortetracycline in plant tissue occurring in a dose dependant manner (Kumar *et al*., 2005). Several studies were recently conducted to evaluate the impact of antibiotics on plant growth and the ability of the plant roots to remediate or degrade antibiotics. In a laboratory model, *Azolla filiculoides* Lam., an aquatic fern known to absorb pollutants, was exposed to sulphadimethoxine for measuring its bioremediation capability. This plant was revealed to actively remove all sulphadimethoxine from water, which indicated that it could be used as a tool for the decontamination of antibiotics (Forni *et al*., 2002). Castro *et al*. (2004) also found that sunflower plant remediated benzotriazoles and its uptake increased as the water temperature increases. Moreover, parrot feather plants (*Myriophyllum aquaticum*) removed 60-100% of the residual antibiotics in water containing up to 10 mg/L oxytetracycline/tetracycline (Gujarathi *et al*., 2005). Phytoremediation technology was effective on the removal of xenobiotics and tetracycline from planted soils (Aprill and Sims, 1990; Gunther *et al*., 1996; Lee *et al*., 2009). However, only few studies are available and indicating that further studies should be done to develop the phytoremediation technology in the future.

Antibiotics Scenario

Because the occurrence of APIs has not been well discovered, the environmental risk associated with antibiotic residuals has been currently emphasized. Preparing API scenarios introduce a proper management technique. Scenarios are commonly used to develop prediction models and enable substance flow analysis by facilitating selection of the proper and most efficient remediation methods at given areas. Essential scenarios that are required to meet the challenge of APIs are listed in Fig. 4. Monitoring is a critical part that must be implemented so that guidelines can be set and systematic data regarding APIs in different environments can be generated. Consequently, biomonitoring and ecotoxicological studies should be conducted using data generated by initial monitoring. The environmental risk assessment of the use, marketing and production of APIs should be done and used to predict the extent of environmental exposure. There are three future approaches that should be implemented to confront the adverse impacts of antibiotics on the environment. The first is that the total amount of antibiotics needs to be reduced through the development of eco-friendly feed additives as alternatives to veterinary antibiotics. The second approach involves increasing public awareness regarding the risks of abused or overused APIs in order to avoid their unnecessary abuse. Similarly, alternative methods of controlling infectious diseases should be also developed to reduce the overall use of APIs and the resistance to antibiotics needs to be under control. For the third approach, novel remediation technologies for the restoration of contaminated sites such as sewage treatment plants, wastewater treatment plants, hospital influents and agricultural soil adjacent to composting facilities should be advanced. Bioremediation is a promising method to degrade APIs with additional safety compared to conventional methods. Among bioremediation technologies, phytoremediation is highly recommended for agricultural soils contaminated with antibiotic residuals. Overall, the aforementioned scenarios should be adapted in harmony with various environmental matrices.

Conclusions

The use of antibiotics in AFOs has received great attention with an increase in the world population. There should be a great deal of concern regarding the detrimental effects of residual APIs on soil, sediment, water and wastewater ecosystems. The long term effects of ARB in the environments contaminated with residual antibiotics also need to be monitored for human health and safety. Additional ecotoxicological studies are required to determine deleterious effects of antibiotic metabolites on plant species near composting facilities. Especially, in Korea, the use of APIs in CAFOs is much greater than in other developed countries. In this article, physiochemical treatments of wastewater, and bioremediation and phytoremediation have been reviewed with recent removal technologies of antibiotic residuals in the surrounding environments. To ensure the effects of APIs on agroecosystems, the monitoring should be required in the future. Furthermore, various scenarios should be well planned and the guidelines need to be developed to properly manage APIs in the environments.

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