ARTICLE IN PRESS

Physics and Chemistry of the Earth xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Residual antibiotics, antibiotic resistant superbugs and antibiotic resistance genes in surface water catchments: Public health impact

Adegoke Anthony A[a,b,*], Faleye Adekunle C[a], Stenström Thor A[a]

[a] SARChI, Institute for Water and Wastewater Technology, Durban University of Technology, Durban 4000, South Africa
[b] Department of Microbiology, University of Uyo, Uyo, Akwa Ibom State, Nigeria

ARTICLE INFO

Keywords:
Antibiotics
Resistance genes
Total antibiotic resistance
Quorum quenching
Internalization
Integrative approach

ABSTRACT

Antibiotics are released to the surface water through different routes, like for example the wastewater treatment plants, from human and animal metabolic waste, agriculture run off, industrial antibiotic waste. The release of the antibiotics to the water catchment and/or the environments in sub-lethal concentrations for the microorganisms lead to the emergence of antibiotic resistance (AR) and selection for antibiotic resistance genes (ARGs). The bacteria utilize their quorum sensing to form biofilm within which ARGs are transferred from antibiotic resistant bacteria (ARB) to the susceptible strains, conferring resistance on them. This has contributed substantially to the growing trend of resistance from multiple antibiotic resistance to extended spectrum resistance, extreme resistance and recently to total antibiotic resistance. The antibiotics, ARB, ARGs are sometimes internalized into the crops irrigated with the surface water returning the bacteria to human in a difficult to control form. While quorum quenching strategy is being advocated during treatment of wastewater to disrupt biofilm as well as the spread of resistance, intermittent check for effectiveness of treatment of wastewater before release into receiving water bodies is hereby advocated. To achieve this, there is the need for better measurements, surveillance and follow-up and thereby the further needs to incorporate more integrative (multidisciplinary) approaches and state of the art tools, for appropriate detection and action. This presentation is to critically review the effect of antibiotic release, ARGs, ARB in water catchment on other water related applications in Southern African countries in relation to other part of the world.

1. Introduction

The surface water bodies are affected by effluents containing pollutants from wastewater treatment plants, storm water overflows and run-off from non-point sources like agricultural land and urban city surfaces. This relates to land-based sources occasioned by run off at wastewater treatment plants rivers (Yang et al., 2011) like in China, where the Yangtze River is heavily affected by organic pollutants (Yang et al., 2008). This also affect the eThekwini Municipality, Kwazulu-Natal Province, South Africa, where impact of wastewater constitute public health importance are residual antibiotics (RAbs) (a.k.a antibiotic residue), antibiotic resistance genes (ARGs), antibiotic resistant bacteria (ARB) or multiple antimicrobial resistant bacteria (MARB) (Li et al., 2011; Agunbiade and Moodley, 2014; Adegoke et al., 2016). Despite the public health importance of the RAbs, ARGs and the emergence of ARB in aquatic microbiomes, very little attention has been accorded to this research area in South Africa. Supplementary research report from other parts of the globes were therefore also reviewed related to the effect of RAbs, ARGs and ARB in water catchment on other water related applications in Southern African countries as well as a few other countries of the world.

1.1. RAbs, ARB and ARGs in surface water bodies in South African and selected African countries

Several factors contribute to the release and persistence of RAbs into surface water. The most important is as the recipients of wastewater effluent containing RAbs and of run offs bringing antibiotics from several sections of the environment to surface water recipients (Xu et al., 2007a; Chang et al., 2010; Bound and Voulvoulis, 2004; Kümmerer, 2009). These RAbs emanate from human or animal excreta. Antibiotics are widely abused by human for therapy, sometimes without physicians' prescription and for veterinary purpose of improving growth of farm animals and in aquaculture (Gómez-Jimenez et al., 2008; Cromwell, 2002). The quantity of antibiotics prescribed in developing countries ravaged by infection are still on the rise, due to immune deficiency or immune suppression caused by human immunodeficient virus (HIV), diabetes and/or cancer. According to

* Corresponding author. Department of Microbiology, University of Uyo, Uyo, Akwa Ibom State, Nigeria.
E-mail addresses: anthonya1@dut.ac.za, aayodegoke@gmail.com (A. Anthony A).

https://doi.org/10.1016/j.pce.2018.03.004
Received 28 March 2017; Received in revised form 1 March 2018; Accepted 22 March 2018
1474-7065/

Table 1
Reported removal efficiencies of RAbs by various technologies.

Technologies	Treatment process	Antibiotic (s)	Efficiencies %	References
Traditional WWTP	Activated sludge	Sulfamethoxazole	60–76 (*CAS 1) − 1–53 (*CAS 2) 37- 40 (^MBR) 70–90 (^MBR)	Polesel et al., 2016
		Pharmaceutical including clindamycin antibiotics	50	Gurke et al., 2015
		Cefaclor	93.9	Watkinson et al., 2009
Modified WWTP	Unspecified	Tetracycline	-(88) to 73	Gulkowska et al., 2008
	Chemically enhanced + Biologically treatment + activated sludge	Norfloxacin	-(16) to 78	
		Trimethoprim	-(42) to 62	
	Activated sludge (AS)	Cefalexin	64.1	Gulkowska et al., 2008
		Sulfamethoxazole	75.7	Batt et al., 2006
			45.2	Lin et al., 2009
	AS + Chlorination	Ciprofloxacin	99.1	Sinthuchai et al., 2016
	AS + UV + Chlorination	Clarithromycin	96.2	
	AS + UV	Clarithromycin	72.1	
	AS + Biological stage – no excess sludge return + Chlorination	Metronidazole	92.3	
Nanotechnology	Carbon membrane coated with nano-TiO2 via a sol-gel process	Tetracycline	100	Liu et al., 2016

*CAS means conventional activated sludge ^ Membrane Bioreactor; UV = ultraviolet couple treatment.

health24.com report of December 2015, there have been a 60% rise in South Africa's antibiotic consumption over the last 10 years. When administered, antibiotics are only partially metabolized but it varies between substances. For some only 10–20% are metabolized while the un-metabolized portions are excreted and disposed through the wastewater treatment plants (WWTPs) into the aquatic environment (Bound and Voulvoulis, 2004; Kümmerer, 2009; Xu et al., 2007b).

Furthermore, most WWTPs have low efficiency to remove RAbs. In fact, some WWTPs record very low removal of RAbs which are usually repertoire of photo-degradation of the RAbs (Chang et al., 2010). Table 1 showed some removal efficiencies for antibiotic removal using some wastewater treatment processes. The reported high degradation of some antibiotics is not owing to the plant efficiency but instability of the particular antibiotics. Absence of effective removal of some RAbs from the WWTPs result in prolonged persistence in the receiving water bodies like surface water, groundwater and drinking water (Yang et al., 2011; Kim and Carlson, 2007; Barnes et al., 2008; Ye et al., 2007). Agunbiade and Moodley (2014) as well as Matongo et al. (2015) reported varying concentration of RAbs in surface water in Kwazulu-Natal, South Africa (Table 1). The origin and effect of the RAbs are further elaborated in 2.0.

Like RAbs in surface water, several studies have confirmed the significant presence of ARB in surface water and drinking water systems (Stenström et al., 2016; Pavlov et al., 2004; Pruden et al., 2006). The presence of ARGs in drinking water was least considered few years back, leading to their reference of ARGs as emerging contaminants (Pruden et al., 2006). Table 2 include some reported ARGs in South Africa and some other selected Africa countries.

The aquatic environment further serves as a platform for the horizontal transfer of ARGs, especially the mobile elements like plasmid and transposon (Tao et al., 2010; O'Brien, 2002; Hunter et al., 2008). This proved the possible transfer of ARGs to the human microbial flora and pathogens. Surface water is therefore increasingly recognised as a reservoir of ARB and ARGs (Baquero et al., 2008; Martinez, 2008; Zhang and Fang, 2009; Hunter et al., 2003).

2. Origin and effect of residual antibiotics, RAs and antibiotic resistance genes (ARGs) in surface water

2.1. Origin of RAs and ARGs in surface water

Pharmaceutical industries leave large residues in the final effluent disposed in surface water bodies. The antibiotics disposed as solid waste can also be washed as run off by rain into the surface water bodies or percolate to groundwaters from dump sites. The effect is global but not many studies have been conducted in this area in developing countries, unlike in the USA and Europe (Hunter et al., 2003). Similar to the pharmaceutical industries are the hospital wastewater outlets and handling of solid waste and the community where RAbs of different used antibiotics for therapy (as discussed in 1.1) are released with the excreta through the sewer system, from on-site sanitation or through open defecation and urination to the surface water bodies.

Large population of immunocompromised individuals (7 million confirmed HIV-positive; 380, 000 new HIV cases in 2014) living in South Africa has led to the high consumption of antibiotics to combat secondary infection and to reduce high resulting mortality. As of 2014, there was a report of about 200,000 South Africans died from the effects of HIV/AIDS. In ten years preceding this 2014 reports, it was estimated that between 42% and 47% of all deaths among South Africans were HIV/AIDS deaths (UNAIDS, 2014; Maurice, 2014). To curtail the effect of several secondary infection, Health24.com reported that South Africa's antibiotic consumption has increased by 60% over the last 10 years.

As far back as 2003, about 9200 tons of antibiotics were used in improving the growth of farm animals in United States (Arikan et al., 2007), while 6000 were used in China (Gay and Gillespie, 2005). Organic fertilizers also contribute large quantity of RAbs to the environment which are washed off to the surface water (Adegoke et al., 2016).

So, varying concentrations of RAbs have been reported by researchers globally in surface water. More closely in South Africa, Matongo et al. (2015) and Agunbiade and Moodley (2014) reported 13.6 μg/L erythromycin and 23.5 μg/L nalidixic acid in surface water (Table 2). In situations where the concentrations of RAbs are higher at the point of wastewater efluents' discharge, these concentrations usually reduce along the line of flow, except when a discharge via run offs occurs mid-way.

Same linear origin of RAbs can also bring ARGs to the surface water bodies. ARGs are used as gene markers in genetically modified (GM) crops (Martinez et al., 2009). Co-transformation with an antibiotic-resistance marker is an important step in making GM plant. The ARGs in these plants may be released to the environment and washed off to the surface water, since the fragments of DNA large enough to contain an ARG may survive in the environment (Martinez et al., 2009). This is however very highly restriced in legislation in developed countries. Table 2 also showed the previously reported ARGs in South Africa including *Tet(A), Tet(B), Tet(E), Tet(M), Tet39, sul3, blaCTX-M-1, qac, sulI and sulII, intI, blaTEM, blaCTX-M-I5 and blaCTX-M* (Stenström et al., 2016; Adegoke and Okoh, 2014; Adesoji et al., 2015; Okolie et al.,