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Antibiotic Residue in the Aquatic Environment: Status in Africa

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Abstract: Information on the presence of antibiotics is sparse for all types of water in Africa, including groundwater, surface water, effluent of wastewater treatment plants (WWTPs) and municipal potable water. With the relatively high sales of different antibiotics to treat infectious diseases in the human population of Africa, the residual of the antibiotics is bound to be released through excretion via urine or fecal matter in parallel to the high sales. This article reviews the published analysis on the occurrence of antibiotics in the environment particularly in the aquatic environment in some countries in Africa. In general, sulfamethoxazole was the most commonly detected in Africa surface water (with eight reports from four countries) at a concentration range of 0.00027 – 39 μgL⁻¹. Wastewater analysis is believed to give an early warning for preventing epidemics. Thus, we discuss the associated level of antibiotic resistance to some prevalent diseases in Africa whose aetiological agents can develop antibiotic resistance due to exposure to antibiotic residue in water. This is important because of rising population of immuno-deficient African residents ravaged by HIV/AIDS, poor nutrition and less efficient sanitation systems.

Keywords: Antibiotic; Environment; Release; Antibiotic resistance.

1 Introduction

Antibiotics are chemicals, which are categorised into three main groups: natural, semi-synthetic and synthetic. They possess the ability either to impede bacterial growth (bacteriostatic) or kill them (bactericidal) [1] and are used in prophylaxis and therapeutics of bacterial induced diseases in both humans and animals. In Africa, opportunistic diseases, such as, tuberculosis (TB), pneumonia and diarrhea are rampant because of immunocompromised conditions predicated by human immunodeficiency virus (HIV) infection (among others), poor sanitation and drug abuse. An increase in the consumption of antibiotics has occurred in order to cure the diseases [2-5], partly without any physician's prescription. Antibiotics are also used extensively in animal farming to maintain the high demand for animal products [6-8]. The high antibiotic consumption in humans and in farm animals [4,9] resulted in increased release of partially metabolized antibiotics into the aquatic environment through wastewater [10]. Most of the antibiotics consumed ends up in sewer system either directly or indirectly, since they are only partially metabolised [1,11,12] or broken down with the active component still intact [13]. Indirect discharge of antibiotics is a result of unintentionally release (via excretion) of consumed antibiotics into the environment. Unconsumed antibiotics are sometimes discarded directly into the sewer system. They are partially degraded but the active components continue to impact the environment, which will eventually enhance resistance in bacteria or may have eco-toxicological effects because of their high concentration [14-16].

2 Occurrence of antibiotics in aquatic milieu

Wastewater treatment plants (WWTPs) receive most of the partially metabolised antibiotics from humans via the sewer system, while the rest are either directly dumped into the nearby streams and rivers or escape as seepages

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from, for example, landfill sites [17]. A general pathway of introduction of antibiotics into the environment is presented in Figure 1. It illustrates the impact of the general society and the eventual contamination of the surface water, which, in the end, affects both drinking water quality and irrigation of crops. Most WWTPs are not configured to remove antibiotics; hence, the antibiotics are released to the aquatic environment from the final treated effluent, making the WWTPs a main hot spot for the release of antibiotics [11,18]. In animal husbandry, manures generated by farm animals are frequently reused as organic fertilizers in farmland and may partially end up in environmental waters through runoff. These waste components contain antibiotics [19] and are major sources of the increase in the concentration of the antibiotics in the aquatic system [20] with attending public health intricacies.

The presence of antibiotics in the aquatic environment, has been confirmed in many reports as emerging contaminants around the world, but the majority of the reports are from outside Africa [10.11.21-23].

2.1 Global detections of antibiotics

Globally, antibiotics are detected at varying concentrations in several environmental matrices such as surface waters and sediment. For example, Karthikeyan and Meyer detected six different antibiotics in raw wastewater in USA. Among these, sulfamethazine was reduced from maximum concentration of 0.21 µg/L in the influent concentration to below detection limit in the effluents. Sulfamethoxazole with an influent concentration (maximum concentration) of 1.25 µg/L was reduced to 0.37 µg/L in the effluent. The remaining 4 are tetracycline, ciprofloxacin, erythromycin and trimethoprim, with their concentrations in the influent and effluent ranging from 0.21- 1.30 μ g/L and 0.85 – 0.14 μg/L respectively [24]. In a wastewater treatment plant in China, L.-J Zhou et al. (2013) detected 20 antibiotics in the influent and 17 in the effluent samples, out of which sulfamethoxazole, norfloxacin, ofloxacin, erythromycin and trimethoprim were most frequently detected [25]. The total concentration of antibiotics per capita in one of the plants investigated ranged from around 500 to 900 μg/d/inhabitant (mean value 670 μg/d/inhabitant) in the influent samples. The corresponding values in the effluent varied from around 130 to 240 µg/d/inhabitant (mean 175 µg/d/inhabitant) [25]. Antibiotics have also been detected in drinking water and purified tap water. This is exemplified in a survey of Austrian drinking water in 2014, where sulfamethoxazole was detected at a concentration

within a range of 4.4 - 8.9 ng/L among many others [26]. Likewise, the presence of 7 sulfonamides, trimethoprim, and 4 macrolides in 37 rivers in Japan was reported [27] and the concentrations were in the range from "not detected" to 630 ng/L with a median of 7.3 ng/L. Similarly, in a treated effluent in Saudi Arabia, sulfamethoxazole and trimethroprim were reported within the range of 145 -730 ng/L and 41- 44 ng/L (mean concentration) respectively [28]. Other reports include different levels of detection of antibiotics in soil and sediment [6,29,30]. Five antibiotics were also detected in plant tissues (chlortetracycline, monensin, sulfamethazine, tylosin, and virginiamycin) with concentrations of <10 µg kg⁻¹ [31]. The adaptation of bacteria to the presence of antibiotics in the environment may lead to emergence of resistance [32] as well as for the selection of antibiotic resistance genes which can be transferred to other bacteria via horizontal gene transfer [33]. This contributes to the increase in the occurrence of antibiotic resistant bacteria (ARB) globally [34] as exposure to sub-lethal concentrations of antibiotics or its derivatives induces resistance [35]. The occurrence have been reported in wastewater, rivers and drinking water in China [36], Europe [37], Australia [38], America [39] and

Adverse effects of the presence of antibiotics in the aquatic environment, especially on fish have been reported [41]. One of the effects, is the suppression of fish immune system by the presence of tetracycline $(0.1 - 50 \mu g/L)$ in environment [42]. Norfloxacin and Sulfamethoxazole at a concentration of 200 µg/L, has also been reported to have an adverse effect on the growth and reproduction rate of Zebrafish [43]. There is a need to monitor and checkmate the release and persistence of antibiotics in the environment.

3 Removal of antibiotics from used waters

The presence and fate of antibiotics in raw wastewater and treated sewage effluents [12,45] are sometimes measured in line with national priorities. In Africa, just a few scattered reports are available, despite the assumed high level of consumption of antibiotics because of high prevalence of infectious diseases [2,4,23,46]. Most studies have focused on the prevalence of antibiotic resistant bacteria in sewage effluents, drinking water and water bodies, with no recourse to inducing factors in relation to the presence of antibiotics in such environments. This leaves an information gap about antibiotics as a potential inducer

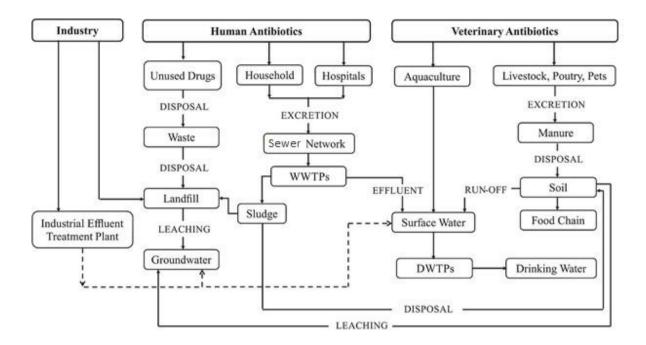


Figure 1: Pathways of antibiotics into the environment [44].

of bacterial resistance. This review gives an overview of available reports of the concentration of antibiotics in the aquatic environment in Africa, their limitations and the need for continuous monitoring of the concentration of the antibiotics discharged into the aquatic environment in relation to antibiotic resistant pathogens.

4 Origin Of Antibiotics Into The Environment

Antibiotics in the environment originate from various sources. The impact of human/animal route, socio-demographic route and other routes are described in the following sections.

4.1 Human/Animal Health Consumption Route Impact

The human consumption of antibiotics is directly related to the residuals released through sewage and waste products discarded into the environment. Based on the level of disease resistance in Africa, it is assumed that the level of antibiotic consumption is high [47].

The information related to the consumption of antibiotics in African countries are scattered and limited.

South Africa and Kenya have a partial record of the amount of antibiotics consumed by their population [9,40]. This partial record is the most comprehensive report on consumption of antibiotics in Africa. Other reports from northern and western Africa are scattered and not comprehensive [4]. Available reports on the global consumption of veterinary related antibiotics with a view on Africa has been documented, giving detailed information on available data on consumption from Kenya only. The report with reference to Mitema et al., reveals that between 1995 to 1999, tetracyclines, sulfonamides and trimethoprim were the most consumed. In South Africa, the quantities of antibiotics prescribed in the private health sector was compiled in a Master's Thesis [48] with a focus on the consumption of fluoroguinolones. The report represents a view on the high rate of consumption of antibiotics in parallel to the prevalent diseases in South Africa.

Detailed information on the use of antibiotics is important for the assessment of the potential concentration ranges that may be released into the environment. This has also been pointed out by the World Health Organisation (WHO) with emphasis on the measurements and monitoring of the volumes and patterns of antibiotics use towards controlling their impact on the environment [49]. In a report on the consumption of antibiotics based on the sales [4] the percentage per capita changes in antibiotics consumption between 2000 – 2010 presented (Figure 2).

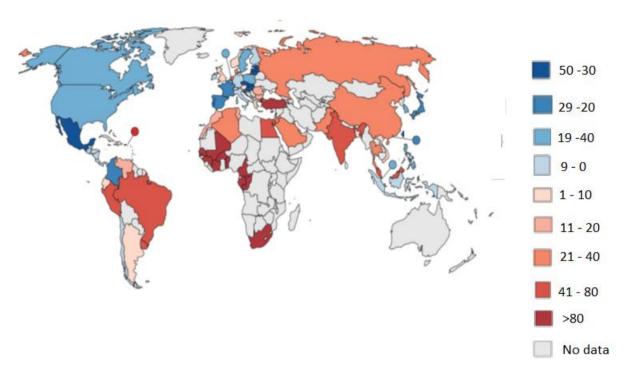


Figure 2: Percentage changes in antibiotics consumption per capita 2000 – 2010 by country. The blue colours indicate decreases while the rest are increases. Picture adapted from [4].

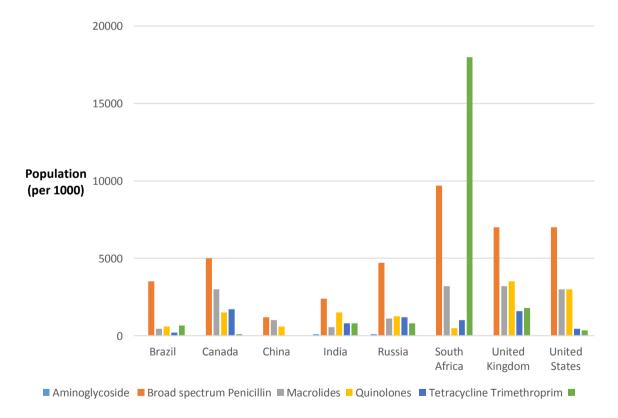


Figure 3: Antibiotics used globally in 2010 based on 1000/population [50].

This shows a global increase in antibiotic consumption spearheaded by low and middle income countries and with a major lack of data from major parts of Africa. Western Africa (French speaking) was considered as one unit and the detailed report from Kenya is missing on the map and also in the text.

Sale records of antibiotics used are fairly accurate in South Africa and can be used as an indicator of the rate of consumption. The broad-spectrum penicillin are the most sold with 18.3% of the antibiotics market followed by penems and carbapenems with 14% and macrolides with 11.1% [51].

A report by IMS as shown in Figure 3 summarizes six groups of antibiotics (aminoglycoside, penicillin, macrolides quinolones, tetracycline and trimethoprim) that are mostly used by humans globally. The use of trimethoprim and penicillin was highest in South Africa and this can be justified based on the pharmacological application of the antibiotics. Penicillin is a broad-spectrum antibiotic while trimethoprim is more specific, and is used in the treatment of bladder infections. When trimethoprim is used with sulfamethoxazole, it can be used for *Pneumocystis pneumonia* in people with HIV/AIDS [52], hence this account for the high rate of sale, and assumed high rate of consumption in South Africa.

The available published report of the use of antibiotics in veterinary medicine is also sparse or lacking for Africa, including South Africa. A report on the mean antibiotics sales per year between 2002 and 2004 are available [53]. In South Africa around 1540 tons of active compounds of five antibiotics were sold. Macrolides and pleuromutilins constituted the major parts of the sales, followed by tetracyclines, sulphonamides and penicillin [53].

The dependence on antibiotics for treatment of bacterial infections has increased over the years, while the bacteria are also constantly evolving in order to adapt to these drugs [54]. This evolution of antibiotic resistance is possibly due to induction through exposure to residual or abused antibiotics. This has led to the development of more resistant bacteria associated with HIV [55]. The scourge of HIV and TB remains of primary concern [56-58] in all reported regions of Africa [59,60], with a direct link to the high rate of HIV infection. Due to a rising proportion of immunocompromised as a result of HIV prevalence, TB has dramatically increased the endemicity of the disease [57]. The world's third largest morbidity of TB is currently in South Africa, driven by HIV infection. In particular, the province of KwaZulu-Natal (KZN) alone accounts for more than 30% of the reported cases.

As a comparison the Northern Cape Province just had a little above 2.3% as the least affected province in

South Africa [2]. Out of the over 100,000 reported cases of TB per year in KZN, well above 60% of the persons are infected with HIV [61]. Invariably, this is associated with high consumption of antituberculosis drugs such as isoniazid and ethionamide (DID, Define Daily Dose per 1000 Inhabitants per Day of 2.41) [48], which in parallel is related to the presence in the environment.

Lung infections caused by bacteria such as Streptococcus pneumoniae is most common in KwaZulu-Natal [62]. When it occurs as a secondary infection to HIV, it may sometimes necessitate the use of multiple antibiotics, as single or fixed dose combination therapy (FDCT) to combat the infection. Nassab and Khosravani reported that approximately 450 million people are infected with pneumonia globally on a yearly basis. This is also a cause of child mortality with close to 2 million deaths yearly [63]. More than half of the global death record, as a result of pneumonia, occurs in Africa and pneumonia ranks as the highest killer infection in South Africa [64,65]. For atypical polymicrobial pneumonia, several antibiotics are usually taken by patients before reporting into a hospital. Usually a high-dose amoxicillin (4 g/day) or amoxicillinclavulanate (4 g/day), or a respiratory fluoroquinolone is the first line of approach [66]. However, combinations of antibiotics are used mostly in the treatment for over a minimum period of two weeks [66].

4.2 Socio-Demographic Impact

Informal settlement communities in Africa do not always have access to direct potable water and are in many instances exposed to unhygienic domestic water and sanitation conditions. The underlying causes are improper sewage disposal or on-site sanitation systems, open defecation, leading to contamination of water sources that later are used for domestic purposes. These life conditions, in addition to poor nutritional status, enhance the risk for different types of diarrheal infections [67]. Diarrhea can be self-regressive after a few days without treatment [68] among the immune-competent, but may be persistent among the immunocompromised or immunosuppressed individuals. Diarrhea disease are prominent in South Africa among children [67] and it is also closely connected to HIV/AIDS. Persistent diarrhea is usually treated with antibiotics such as metronidazole. The use of this drug is increasing within a growing population that lack basic social amenities [67].

Partially metabolized antibiotics in the environment [34] may increase the development of antibiotics resistant microbes [36,69] and eco-toxic effects [70]. Direct dumping

of antibiotics into the sewer system also contributes to their increase in the environment. Hamjinda et al. reported that most of the oral drugs used by patients in hospitals are discarded into the sewer system, thereby contributing to the concentration of antibiotics in most hospital wastewater effluents [71]. Likewise, derivatives formed from wastewater treatment reactions may create a more toxic effect than its real natural form [18].

Another important group of antibiotics are the antiparasitic drugs. These are used to treat infections with multicellular parasitic worms (helminths) and unicellular parasites (protozoans). They are of major importance in both human tropical medicine and in veterinary medicine. The presence of the active component of anti-helminthic drugs (AHD) are well documented in animal tissues and products such as milk, liver, muscle, kidney [72-75] but less so from environmental sources.

Considering the high number of animal husbandry farms in many provinces, with reports of AHD resistance rampant in animal farms in South Africa [76,77], the probability of having a high concentration of these drugs in wastewater or their receiving water/sediment is high. There is a significant risk that anti-helminthic agents may affect freshwater organisms negatively in the environment [78,79]. These antibiotics are mostly entering the aquatic environment via wash off from grazing farmlands or from where animal manure are applied or stored [80]. In promoting the reasons for the widespread use of drugs to control human helminths, Cerami and Warren suggested that "helminths are less likely to develop resistance or would do so more slowly" compared to other infectious agents because they multiply at a lower rate [81]. This has certainly not appeared true for helminths in livestock, and neither in the treatment of human helminths as well. It is also estimated that some 1.3 to 2.0 billion people in the world suffer from helminthic infections [82,83]. Drug resistant helminths may not be a major health issue yet, but may be of possible future environmental concern.

5 Current Level Of Threat Associated With Antibiotics' Resistance

The rate of development of Multidrug Resistant (MDR) and Extensively Drug Resistant (XDR) bacteria is alarming and there is a need for a holistic approach towards the management of the crisis [84,85]. Klopper et al.showed that TB bacteria are resistant to the available antibiotics, both first and second line approaches [86]. Likewise MDR pneumonia has been identified [87].

a recent study from South Africa on MDR TB, the empiric treatment approach (rudimentary treatment without consideration of the environment) in administration of drugs maybe lead to poor therapeutic outcome, thereby fuelling the development of XDR [61]. Different approaches towards the elucidation of the cause of the poor performance of the antibiotics in the treatment of TB seem to have been taken, except the role of residues of antibiotics on microbes in the environment. Antibioticresistant pathogens have been detected in tap water and purified water [88]. In relation to this, the possibility of the influence of resistant pathogens from the environment on the pathogens in an immunocompromised patient may be the reasons for the failure of the drug of approach. Mycobacterium tuberculosis, which is documented in wastewater, may get exposed to the antibiotic residue and develop resistance [89] to form XDR M. tuberculosis. Exposure of the XDR bacteria excreted into wastewater, with the wastewater already containing residual antibiotics in sub-lethal concentrations, might have contributed to the emergence of Total Drug Resistance (TDR). Intermittent surveillance of the residual antibiotics in the environment will contribute to the documentation of emergence of resistance and selection for resistance genes [34].

MDR pneumonia-causing bacteria have been reported in South Africa [87]. Cases of gradual increase in threat level of resistance towards antibiotics in the treatment of different diseases have been reported and are exemplified in Table 1. Exposure of pneumonia bacteria to subinhibitory concentration of antibiotic residues in the environment may play vital role in the emergence of the MDR.

The resistance to antibiotics used in the treatment of pneumonia was compared between 2007 and 2014 in South Africa [92] and a gradual increase was noticed. Cefotaxime increased from 46% to 68%, Cefepime from 44% to 68% and Ciprofloxacin from 31% to 46% [91,92]. This increase may not represent a general trend, but there is in fact an increase in the rate of resistance that should not be overlooked.

A study conducted on children under five years in Mozambique showed a steady build-up of resistance to all antibiotics used in treatment of diarrhea caused by Shigella bacteria [96] (Table 1). In an extensive review on the antibiotic resistance of Shigella across Europe, Asia and Africa, it was reported that the rapidly rising trend of antibiotic resistance were similar, with resistance towards the second line of the antibiotics [97]. One of the recommendations made at checkmating these increases in antibiotic resistance is to intensify research towards

896 — A.C. Faleye et al. DE GRUYTER

Table 1: Some bacterial diseases and reported antibiotic resistant statues.

Diseases (causative bacteria)	Current stage of resistance to antibiotics	Drug of approach (percentage resistance)	Study location	References
Pneumonia (Klebsiella pneumoniae)	MDR	Amoxicillin (99), Amox/clav (14), Cefuroxime (27), Cotrimoxazole (11)	Gauteng, Western cape, Eastern cape, Kwazulu-Natal, Mpumulanga, and Orange free state provinces in South Africa	[90]
Pneumonia (Klebsiella pneumoniae)	MDR	Ampicillin (98), Cefuroxime (52) Ceftriaxone/cefotaxime (46) Cefepime (44), Co-amoxiclav (52) Piperacillin-tazobactam (40) Ciprofloxacin (31) Levofloxacin (32), Ertapenem (2) Imipenem (0), Meropenem (0)	Johannesburg, Pretoria, Durban, Cape Town and Bloemfontein all in South Africa	[91]
Pneumonia (Klebsiella pneumoniae)	MDR	Cefotaxime (68.3), Carbapenens (4.5), Piperacillin/tazobactam (33.1), Ceftazidime (68.3), Cefepime(68.3), Ciprofloxacin (46.5)	Gauteng, KwaZulu-Natal, Free State, Limpopo and Western Cape provinces of South Africa	[92]
Pneumonia (Streptococcus pneumoniae)	MDR	Ampicillin (74), Chloramphenicol (55), Cotrimoxazole (66), Gentamicin (16), Chloramphenicol (35), Ampicillin plus gentamicin (14), Penicillin plus gentamicin (11), Chloramphenicol plus ampicillin (29).	Maputo Provinces in Southern Mozambique	[93]
Pneumonia (Streptococcus oneumoniae)	MDR	Penicillin (46), amoxicillin (7), Amox/clav (5), Cefuroxime (53), Azithromycin (61), Clarithromycin (61), Cotrimoxazole (51)	Gauteng, western cape, Eastern cape, Kwazulu-Natal, Mpumalanga, and Orange free state provinces in South Africa	[90]
Pneumonia (Streptococcus pneumoniae)	MDR	Chloramphenicol (33), Clindamycin (10), Erythromycin (1.5), Gentamicin (85.2), Oxacillin (18.6), Tetracycline (50.8), Trimethroprime (89.4)	Lilongwe district Malawi.	[94]
Shigellosis a. (<i>S. flexneri</i> type 2a), b. (<i>S. flexneri</i> type 1b)	MDR	Ampicillin a (66.3), b (85.4) Chloramphenicol a (47.2), b (77.1) Streptomycin a (69.7), b (85.4) Sulfamethoxazole a (91.0) Trimethoprim a (94.4), b (75.0) Tetracycline a (60.7), b (100) Nalidixic Acid a (1.1), b (89.6) Ciprofloxacin a (0), b (0) b-lactamase based a (2.3), b (2.1)	All nine provinces in South Africa	[95]
Shigellosis	MDR	Ciprofloxacin(0), Ceftriaxone (0) Co- Trimoxazole (83), Tetracycline (72), Ampicillin (26).	Gauteng, South Africa	[23]
Shigellosis	MDR	Chloramphenicol (52), Ampicillin (56), Tetracycline (66), Trimethoprim (84), Sulfamethoxazole (84).	Southern Mozambique, Mozambique.	[96]

identifying and removal of sub lethal concentration of antibiotics or their active components from the environment, particularly in wastewater [49]

6 Detection Of Antibiotics In **Aquatic Environment**

Among African countries, South Africa is the country with the highest number of studies monitoring antibiotic use (Table 2). Still, antibiotics in the aquatic environment of South Africa has only been addressed in a limited number of studies and not directly been compared to the level of infectious diseases. Likewise globally, such comparisons are few. Only ten antibiotics, out of the numerous antibiotics consumed have been detected in two out of the nine South African provinces. Their concentrations and references are displayed in Table 2. The information from other African countries are even more limited. There are only 15 published studies having a limited amount of information, despite generally high sales/consumption on the African continent.

An important factor related to the information of antibiotics detected in a country is the sampling coverage area. Analysing a large number of antibiotics from different geographical locations gives more information about the environmental concentration within the country. This is much better than identifying a large number of antibiotics in one sampling spot. For example, a total of 13 antibiotics have been identified in Nigeria representing two sampling areas in the Western region of Nigeria [103,104]. In the first report, only one antibiotic was detected by Olaitan et al., and in the second report, 12 antibiotics were identified by Olarinmoye et al. [103,104]. Based on the sampling, only from the Western region, this report cannot represent the level of antibiotics in the whole country. Nigeria is the most populated country in Africa with a large proportion living on below \$1 per day [97]. Such low income standards are associated with malnutrition, high diseases burden, and correlated with high rate of drug consumption [110]. Hence one would assume that further reports would be available, based on the influencing factors and accounting for the antibiotics on this large population. Reports on the environmental presence of antibiotics from other West African countries are also largely lacking. From the North African countries, reports are available from Morocco, Tunisia and Egypt [105-108]. Analyses were performed on potable water in Morocco with one antibiotic detected. In Egypt and Tunisia, three and sixteen antibiotics were detected respectively in wastewater samples. The first

five antibiotics detected in Tunisia [106] were identified in wastewater at ng/L levels of concentration, while the remaining 11 antibiotics were detected in wastewater/ seawater in ng/mL [107]. The differences in the results of the analyses cannot be compared because, different antibiotics were analysed. East Africa is represented by the analysis of 10 antibiotics from Kenya, while in Southern Africa, 11 antibiotics were detected (South Africa with 10 antibiotics and Zimbabwe with 1 antibiotic).

A different range of concentration of antibiotics was reported by United Nations (UN) global surface water assessment for pharmaceuticals, when compared to the reported concentrations in Africa [111]. For example, sulfamethoxazole, the most reported antibiotic, was reported in South Africa at a concentration of 7.3 µgL⁻¹ [46], while in Nigeria the reported concentration was 1.5 µgL⁻¹ [103] while the minimum and the maximum concentrations reported in Africa were at a concentration of 0.00027 μgL⁻¹ in Tunisia and 40 μgL⁻¹ in Kenya [102], respectively. However, the minimum and maximum concentrations reported by the UN were in the range of 0.1 - 29 µgL⁻¹, respectively [111]. Likewise, ciprofloxacin was reported within the range of 19 – 6500 μgL⁻¹ by the UN [111] and 0.0002 - 15 µgL⁻¹ in Africa from Tunisia [106] and South Africa [23], respectively. These measurements do not correlate with concentrations detected in Africa because most of the measurements used for the calculation were made without reports from Africa, as there are few reports from the continent.

Globally, Quinolones and flouroquinolones are antibiotics that are frequently used for the treatment of bacterial infections and they are also among the five (β-lactam, macrolides, fluoroquinolones, sulfonamides, and tetracyclines) most commonly detected in the environment [112]. In a study on a wastewater reclamation plant (WRP) in Beijing, China, [113], 0.1 μgL⁻¹ of flouroguinolones were detected at the tertiary effluent. The concentration was similar to findings in South Africa by R. Hendricks and E.J. Pool but much lower than what was found in the surface/sediment analysis (15µgL-1 and 190 µg/g) by Agunbiade and Moodley [23,98].

Further information on the detection of antibiotics within the African environment will be beneficial for several reasons: 1) To answer questions related to correlations of population density and socio-economic strata as compared to consumption of antibiotics and concentrations in surface water and ground water; 2) To relate sewer system and poor method of sewage disposal with different barriers and release routes of residual antibiotics in the wastes. This may also contribute to an assessment of the accumulation of antibiotics in the

898 — A.C. Faleye et al. DE GRUYTER

Table 2: Antibiotics and their detected maximum concentrations reported in the environment in Africa (the number of significant digits has been reduced from what was stated in the respective reference).

Sample sources	Study location	Antibiotics (Class)	Maximum Conc.	Literature
Treated sewage	South Africa	Fluoroquinolones (Quinolones)	0.12	[98]
Effluents(µgL-1)		Sulfamethoxazole (Sulfonamide)	0.15	
Surface water (µgL-1)	South Africa	Ampicillin (Penicillin)	16	
		Ciprofloxacin (Quinolones)	15	[23]
		Nalidixic acid (Quinolones)	23.50	
^a Sediment (ngg ⁻¹)	South Africa	Ampicillin (Penicillin)	a467	[23]
		Ciprofloxacin (Quinolones)	^a 187	
		Nalidixic acid (Quinolones)	a104	
Surface water (µgL-1)/	South Africa	Sulfamethoxazole (Sulfonamide)	7.3/°50	[46]
^a Sediment (ngg ⁻¹)		Erythromycin (Macrolide)	20/°16	
		Sulfamethazine (Sulfonamide)	33 / ^a ND	
		Metronidazole (Nitroimidazole)	ND / ^a 63	
		Trimethoprim (Trimethoprim)	3.70 / aND	
Surface water (µgL-1) /	South Africa	Sulfamethoxazole (Sulfonamide)	6 /a< MDL	[46]
Sediment (ngg-1)		Erythromycin (Macrolide)	13.6/a <mdl< td=""><td></td></mdl<>	
(00 /		Sulfamethazine (Sulfonamide)	4.6 / aND	
		Metronidazole (Nitroimidazole)	ND / a130	
		Trimethoprim (Trimethoprim)	0.80 / a92	
River water (µgL-1)	South Africa	Nalidixic acid (Quinolones)	3.0	[99]
Surface water (µgL-1)	South Africa	Azithromycin (Macrolide	0.03	[100]
Juliace water (µgL)	Jouth Africa	Clarithromycin (Macrolide	0.30	[100]
		Sulfamethoxazole (Sulfonamide)	1.31	
		Sulfasalazine (Sulfonamide)	0.07	
			1.20	
D' / / / /		Trimethoprim (Trimethoprim)		[404]
River water/ Wastewater	Kenya	Sulfamethoxazole (Sulfonamide)	14 / 3	[101]
(μgL ⁻¹)		Ciprofloxacin (Quinolones)	0.50 / 0.07	
		Trimethoprim (Trimethoprim)	2.70 / 0.07	
River water/ Wastewater	Kenya	Chloramphenicol (Amphenicol)	0.70 / 0.20	[102]
(μgL ⁻¹)		Ciprofloxacin (Quinolones)	ND / 0.30	
		Levofloxacin (Quinolones)	0.04 / 1.60	
		Metronidazole (Nitroimidazole)	4/3	
		Nalidixic acid (Quinolones)	ND / 2.80	
		Sulfadoxine (Sulfonamide)	1460 / 3.20	
		Sulfamethazine (Sulfonamide)	0.60 / ND	
		Sulfamethoxazole(Sulfonamide)	40 / 10	
		Trimethoprim (Trimethoprim)	7 / 4	
River water (µgL·1)/	Nigeria	Chloramphenicol (Amphenicol)	0.40 / aND	[103]
Sediment (ngg-1)		Chlortetracycline (Tetracycline)	0.10 / aND	
		Clarithromycin (Macrolide)	0.10/ a43	
		Doxycycline (Tetracycline)	0.10 / aND	
		Erythromycin (Macrolide)	1 / ^a 147	
		Oxytetracycline (Tetracycline)	0.10 / aND	
		Roxithromycin (Macrolide)	0.02 / ^a 10	
		Sulfadiazine (Sulfonamide)	0.04	
		Sulfadimidine (Sulfonamide)	0.01	
		Sulfamethoxazole (Sulfonamide)	1.50/a11	
		Tetracycline (Tetracycline)	0.10	
		Trimethoprim (Trimethoprim)	0.40 / ^a 38	
		Azithromycin (Macrolide)	ND /a10	
Ground and Surface water (μgL-1)	Nigeria	Ciprofloxacin (Quinolones)	0.90	[104]
+Wastewater(µgL-1)	Egypt	Amoxicillin (Penicillin)	99400.0	[105]
	071: ·	Ampicillin (Penicillin)	70600.0	[]
		Dicloxacillin (Penicillin)	119400.0	

Continued Table 2: Antibiotics and their detected maximum concentrations reported in the environment in Africa (the number of significant digits has been reduced from what was stated in the respective reference).

Sample sources	Study location	Antibiotics (Class)	Maximum Conc.	Literature
**Wastewater	Tunisia	Erythromycin (Macrolide)	< 0.01	[106]
(μgL ⁻¹)		Clarithromycin (Macrolide)	< 0.01	
		Ofloxacin (Quinolones)	< 0.01	
		Ciprofloxacin (Quinolones)	< 0.01	
		Sulfamethoxazole (Sulfonamide)	< 0.01	
Wastewater / Seawaters	Tunisia	Chloramphenicol (Amphenicol)	3.30 / 15.60	
(μgL ⁻¹)		Thiamphenicol (Amphenicol)	1.20 /ND	[107]
		Florfenicol (Amphenicol)	3.30 / 18.4	
		Paromycin (Aminoglycoside)	4.2 / ND	
		Kanamycin (Macrolide)	7.50 / 1.50	
		Aparamycin (Aminoglycoside)	1.50 / 1.80	
		Streptomycin (Aminoglycoside)	2.70 / 3.40	
		Amikacin (Aminoglycoside)	2.30 / 1.20	
		Sisomycin (Aminoglycoside)	6.70 / 0.40	
		Neomycin (Aminoglycoside)	16.4 / 0.70	
		Gentamycin (Aminoglycoside)	1.60 / 1.40	
Potable water (µgL-1)	Morocco	Sulfamethoxazole (Sulfonamide)	290.0	[108]
Surface water (µgL-1)	Zimbabwe	Oxytetracycline (Tetracycline)	150.0	[109]

^{* =} Concentration was originally in mg/L, ** = Concentration was originally in ngL*1, ND = Not detected, a = sediment sample

environment; 3) To promote laboratory capacity which may be essential for future assessment of the environmental presence and impact of pharmaceuticals in general.

Conflict of interest: The authors declare no conflict of interest.

7 Conclusion

Efforts to address the misuse and overuse of antibiotics in both the human and animal health sectors in Africa must be intensified to sustain the efficacy of the remaining potent antibiotics. Creating more awareness about the negative impact of misuse in relation to antibiotic resistance would reduce drug abuse to a large extent. Antibiotics released into wastewater have to be appropriately tracked. The sewer system must include facilities with modern wastewater treatment technology, which will be focused towards the removal of antibiotics and other nanocontaminants from wastewater, while already exposed microbes should be totally exterminated from treated water, with the use of post-treatment technology, before use.

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