Occurrence and Removal of Three Antibiotics in Two Wastewater Treatment Plants in Morogoro Municipality, Tanzania

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Abstract: Urban wastewater treatment plants (UWTPs) are among the main sources of antibiotics release into various compartments of environment worldwide. These antibiotics have aggravated increasing anxiety, particularly as no legitimate requirements have been set for discharge into surface water bodies of these ubiquitous, persistent and biologically active substances. Massive quantities of antibiotics are used in human and veterinary medicine in all parts of the globe to treat diseases with bacterial, fungal and parasitic origins. These are also largely used in animal operations for growth promotion and for disease prophylaxis. These are often partially metabolized depending on type of antibiotics. After administration a significant fraction of the antibiotic can be excreted as a parent compound, metabolites or in conjugate forms that can be converted back to parent antibiotic. The residual antibiotics from human and animal use can enter the environment via various pathways, including wastewater, runoff from land in which manure or human waste has been applied and leaching. In this study occurrence and removal of three selected antibiotics, tetracyclines, sulfonamides and quinolones were studied in two large wastewater treatment plants in Morogoro Municipality using ELISA technique. Results indicated that the highest mean concentrations were 27.275±2.83878µg/l, quinolones 48.7615±7.9343µg/l tetracyclines and 18.7492±5.4906µg/l sulfonamides. The elimination of antibiotics through these wastewater treatment plants was incomplete. The removal efficiency was 28.50% tetracyclines, 11.33 % quinolones and 82.32% sulfonamides at mafisa wastewater treatment plant. At Mzumbe wastewater treatment plant removal efficiency was 2.5% tetracyclines, 7.259% quinolones and 2.28% sulfonamides.

Keywords: Antibiotics, Removal, wastewater, Morogoro, Tanzania

1. Introduction

As a class of emerging environmental micropollutant contaminants, antibiotics have been of increasing concern over the past decade. Antibiotics play an important role in treating and preventing diseases in humans and animals. The overuse of antibiotics sometimes is inevitable in preventing and treating infectious diseases in humans and animals. Antibiotics are also used as growth promoters in livestock and aquaculture. Approximately 210 million kilograms of antibiotics are produced annually in China (Su et al., 2012) and 16 million kilograms of antibiotics are used annually in the USA (United States of America) for human and agriculture use (Sarmah et al., 2006).

Antibiotics are only partially absorbed after administration, and nearly 75% of antibiotics are excreted as original compounds or metabolites by humans and animals (Luo et al., 2011). After consumption, such antibiotics are eventually discharged in the environment through wastewater discharge, sewage effluent, most in their original form (Kummerer, 2009; Larson et al., 2007, Threedeach et al., 2012). In the environmental waters, the long-term residues of antibiotics may cause potential risks to the aquatic organisms (Liu et al., 2009) and may lead to occurrence and prevalence of biological resistance genes (Tao et al., 2010). Also antibiotic residues generate selective pressure to bacteria in the environment, thus contributing to proliferation of antibiotic resistance genes. The occurrence of antibiotic resistance changes the composition and structure of microbial community and increase the potential risks to humans health and environment (Kim et al., 2004; Akinbowale et al., 2007). Once bacteria acquired antibiotic resistance can compromise the effectiveness of antibiotic therapy.

Li and Zhang, 2011; Leung et al., 2012; Aydin and Tahli, 2013 have gathered extensive literatures on the concentration levels of pharmaceuticals in aqueous phases such as wastewater and surface water. In wastewater treatment plants removal percentage, which is based on concentrations of pharmaceuticals in the influent and the effluent is the only parameter available for calculating the pharmaceutical removal efficiency in wastewater treatment plants currently (Leung et al., 2012).

Aquatic environments made by (or just influenced by) humans may serve as a reservoirs for antibiotic resistant genes (Negreanu, 2012). Even antibiotic concentrations below minimal inhibitory concentration (MIC) can promote development of resistance (Gullberg, 2012). This suggest that occurrence of trace amounts of antibiotics into environment may generate an increase in development of antibiotic resistant bacteria (Negreanu, 2012). But the permissible levels of antibiotics in environmental waters are still not yet established. As plenty of antibiotics flowing into rivers, wastewater treatment plants, soils and manure, probably can affect the environment, hence persistent exposure to antibiotics to humans, animals and aquatic organisms at low
From the figure above, antibiotics from households and non domestic points like industries, hospitals and services move to wastewater treatment plants, finally to surface water and soil. From soil move to ground water through leaching. Ground water is used as a source of drinking water, hence are taken back by humans and animals through drinking water. Also biosolids from animals and aquaculture antibiotics are taken to surface water, move to drinking water treatment plants and taken by humans and animals through drinking water.

2. Materials and Methods

2.1. Location

Mafisa and Mzumbe wastewater treatment plants are located in Morogoro municipality, Tanzania. Mafisa wastewater treatment plant has eight ponds which are connected from entry (first) to the exit (eight), Mzumbe wastewater pond has only three ponds, but also connected together from the entry (first) to the exit (third). Morogoro is town with approximately 2,218,492 inhabitants according to 2012 census located 200km km inland from Dar es Salaam. Mafisa is located next to the Morogoro river in northern part of the city, in an area with housing and farming, receives wastewater from the city of Morogoro. The mafisa wastewater treatment system consists of two receiving ponds (gravity receiving pond and track receiving pond) and six sedimentation ponds. While pond one is anaerobic pond, second pond is aerobic stabilization pond, ponds three, four, five and six are stabilization maturation ponds. The ponds have different functions as well as different dimensions. The dimension, flow rate and pH are summarized in Table 1.
Erba). pH was measured using universal pH indicator strips. The samples were transported to laboratory within one hour where they were filtered twice. The first filtration was through a grade 5 filter paper from Munktell with particle size retention of 20µm. The second filtration was through a grade 120H filter paper also from Munktell with particle size retention of 1-2µm. After filtration the samples was divided into 2x 800ml amber bottle.

2.3 Solid phase extraction

800 ml water sample, pH adjusted to 3 was loaded into Oasis® HLB 6m³ 200mg (30ml) cartridges from Waters (Milford, MA, USA) using a vacuum manifold and pump. The vacuum manifold was a VacMaster from IST (Sweden) and the pump was from ScanVac (Denmark). The drop rate was adjusted to 1.5ml/min. Prior to loading cartridges were preconditioned with 2ml MeOH followed by 2ml distilled water. After loading the samples and cartridges were air-dried using vacuum and stored at -18°C before analysis.

Prior to analysis, antibiotics were eluted from cartridges with 8ml (formic acid in MeOH) after washing with 2ml 5% MeOH in water. The eluent was evaporated to dryness under a gentle stream of nitrogen at 33°C. Afterwards, the samples were reconstituted to 100µl (0.01% formic acid in MeOH) and 900µl water. Elution and evaporation was done in 12ml amber bottles. Samples were then transferred to eppendorf tubes centrifuged and supernatant were used for analysis.

2.4 Chemicals/Reagents

Pure antibiotics salts of sulphonamides, tetracyclines and quinolones were purchased from Sigma -Aldrich (Augsburg, Germany). Ridascreen kits (Ridascreen sulfonamides (R3004), Ridascreen tetracyclin (R3505) and Ridascreen quinolones/quinolones (R3113) were purchased from R-Biopharm AG, (Darmstadt, Germany). Analytical grade methanol was purchased from Sigma-Aldrich (Augsburg, Germany).

2.5. Enzyme-linked immunosorbent Assay Basis

2.5.1 Sulphonamides

The basis of the test was antigen-antibody reaction. The microtitter wells were coated with capture antibodies directed against anti-sulphonamide antibodies. Standard or sample sulphonamides conjugate and anti-sulphonamide antibodies solutions were added. Free sulphonamides and sulphonamide conjugate compete for the sulphonamides antibody binding sites (competitive enzyme immunoassay). At the same time, the anti-sulphonamide antibodies were also bound by the immobilized capture antibodies. Any unbound conjugate was removed in washing step. Substrate/chromogen was added to the wells and incubated. Bound conjugate converted the chromogen into a blue product. The addition of the stop solution changed colour from blue to yellow. The measurement was made photometrically at 450 nm using ELISA reader. Absorption was inversely proportional to the sulphonamides concentrations in the sample.

2.5.2 Tetracyclines

The basis of the test was antigen-antibody reaction. The microtitter wells were coated with tetracycline-protein-conjugate. Tetracyclines standards or sample solutions and anti-tetracycline antibodies were added. Free tetracyclines and immobilized tetracyclines compete for tetracyclines antibody binding sites (Competitive Enzyme immunoassay). Any unbound antibody was removed in washing step and enzyme labelled secondary antibody, which was directed against the anti-tetracycline antibody was added. After removing unbound enzyme labelled antibodies by a washing step, substrate/chromogen was added to the wells and incubated. Bound conjugate converted the chromogen into a blue product. The addition of the stop solution changed colour from blue to a yellow. The measurement was made photometrically at 450 nm using ELISA reader. The absorption was inversely proportional to the tetracyclines concentration in sample.

2.5.3 Quinolones

The basis of the test was antigen-antibody reaction. The wells were coated with a capture antibodies directed against anti-quinolones antibodies. Standards or sample solutions of ciprofloxacin enzyme conjugate and anti-quinolones antibodies were added. Free quinolones and ciprofloxacin conjugate compete for the quinolones antibody binding sites (Competitive enzyme immunoassay). At the same time the anti-quinolone antibodies were also bound by the immobilized capture antibodies. Any unbound conjugate was removed in washing step. Substrate/chromogen was added to the wells and incubated. Bound conjugate converted the chromogen into a blue product. The addition of stop solution changed colour from blue to yellow. The measurement was made photometrically at 450 nm using ELISA reader. Absorption was inversely proportional to the quinolones concentrations in the sample.

3. Analytical Procedure

3.1 Sulphonamides

Fifty microliters of each standard or prepared sample were added to microplate wells of ELISA plate in duplicate. Fifty microliters of conjugate was added to each well. Then fifty microliters of antibody was added to each well mixed gently. The mixture was incubated for one hour at room temperature. The solution in the wells was discarded and the microplate was tapped three times in blotting paper to ensure complete removal of solution from wells. The wells were filled with 250µl of washing buffer. The liquid was poured out and the wash step was repeated three times. One hundred microliters of substrate/chromogen was added to each well, incubated for 15 minutes at room temperature in the dark. One hundred microliters of stop solution was added. Absorbance was read at 450 nm using ELISA reader.

The results of were expressed in percentages of the maximum absorbance (B/B0%) using the following equation.

$$\text{Absorbance at Zero standard concentration} = \frac{B}{B_0} \times 100$$
B/B0% values were interpolated on the calibration curve built with six sulfonamide standard solutions (0, 1, 3, 10, 100µg/l). Multiplied by dilution factor to obtain the final concentrations of sulfonamides.

3.2 Tetracyclines

In order to obtain the tetracycline concentrations in the sample, the B/B0% values were interpolated on the calibration curve built with six tetracycline standard solutions (0, 0.05, 0.15, 0.3, 0.6 and 1.8µg/l). Multiplied by dilution factor to obtain the final concentrations of tetracyclines.

3.3 Quinolones

In order to obtain the quinolone concentrations in the sample, the B/B0% values were interpolated on the calibration curve built with six tetracycline standard solutions (0, 0.5, 1.5, 3, 6 and 18µg/l). Multiplied by dilution factor to get the final concentrations of the quinolones.

4. Results and Discussion

4.1. Recovery and Detection limit

Recovery rates were 70-87%, 75-114% and 80-110% for sulfonamides, tetracyclines and quinolones respectively, these rates were within the range stated in ELISA kits used. The detection limit of the method ranged from 1.5µg/l, 1.2µg/l and 0.5µg/l sulfonamides, tetracyclines and quinolones respectively.

Table 2: Mean concentrations of antibiotics and removal efficiency at Mafisa wastewater treatment plant

<table>
<thead>
<tr>
<th>Antibiotic</th>
<th>Cluster</th>
<th>Mean</th>
<th>Removal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quinolones</td>
<td>Cluster 1</td>
<td>27.2753±2.83878</td>
<td>11.33%</td>
</tr>
<tr>
<td></td>
<td>Cluster 2</td>
<td>24.0660±5.1280</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cluster 3</td>
<td>24.1841±2.14841</td>
<td></td>
</tr>
<tr>
<td>Tetracyclines</td>
<td>Cluster 1</td>
<td>48.7615±7.9343</td>
<td>28.50%</td>
</tr>
<tr>
<td></td>
<td>Cluster 2</td>
<td>41.5620±8.43186</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cluster 3</td>
<td>34.8635±5.17469</td>
<td></td>
</tr>
<tr>
<td>Sulfonamides</td>
<td>Cluster 1</td>
<td>18.7492±5.4906</td>
<td>82.32%</td>
</tr>
<tr>
<td></td>
<td>Cluster 2</td>
<td>10.3945±1.77246</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cluster 3</td>
<td>3.3136±1.35145</td>
<td></td>
</tr>
</tbody>
</table>

Table 1, shows that the concentrations of antibiotics generally was high in the first cluster and low in the third cluster. Also mean concentrations of tetracyclines was high followed by quinolones, while the concentration of sulfonamides was lowest among the three antibiotics. There was a reduction of antibiotics concentrations from influent, maturation and exit ponds ,more was for sulfonamides (figure 2, 3 and 4).
Operational factors that can influence the biological removal efficiencies for antibiotics appear to vary with efficiency. Compare to tetracyclines and quinolones, these drugs are easy to be degraded during aerobic decomposition. Electron donor acceptor interactions. Normally sulfonamides are easy to be degraded during aerobic decomposition compared to tetracyclines and quinolones. Hence high removal efficiency.

Concentrations of antibiotics in the influents and effluents are summarized in Table 2. All the target antibiotics were detected in samples. The selected antibiotics were tetracyclines, sulfonamides and quinolones. Among the three selected antibiotics, concentrations of tetracyclines were high, followed by quinolones, probably because these drugs are commonly used in human and veterinary medicine for treating different infectious diseases. Also these two drugs are difficult to degrade compare to sulfonamides.

The concentrations of detected antibiotics were higher than those detected in different studies in the world, like USA (Meyer et al., 2006), Australia (Watkison et al., 2007), Beijing, China (Chang et al., 2008), UK (Kasprzyk-Horden et al., 2008), Switzerland (Gobel et al., 2005) and Fjian, China (Zhang et al., 2015). This might be due to poor removal efficiency of the studied wastewater treatment plants.

5. Discussion

Wastewater treatment plants play an important part in the life cycle of antibiotics in society, and their removal may influence the surrounding environment. Except for antibiotics application in livestock, followed by fertilization with manure (Zarfl et al., 2009) and direct discharge of wastewater from livestock and human (Tang et al., 2015), the removal efficiency of wastewater treatment plants could be another important reason for the presence of antibiotics in the environment (Watkison et al., 2009; Zhang et al., 2015).

In this study the removal efficiency of all selected antibiotics was high at Mafisa wastewater treatment plant than at Mzumbe wastewater treatment plants. The removal efficiency at Mafisa wastewater treatment plants was higher for the sulfonamides, followed by tetracyclines and lowest for quinolones. At Mzumbe wastewater treatment plants the removal efficiency was high for quinolones, but for both sulfonamides and tetracyclines was low and generally the removal efficiency at Mzumbe wastewater treatment plant is poor. From this study it is clear that the Mafisa wastewater treatment plant system is efficient in removing antibiotics, probably due to a large number of sedimentation and maturation ponds compared to Mzumbe wastewater treatment plant. Hence Mafisa system can be adopted for wastewater treatment in developing countries.

For tetracyclines, the removal efficiency ranged from 25.62% to 50.74% in Jiulongjiang River Basin, in South China. In USA tetracycline have been reported after secondary treatment and chlorination with removal efficiencies of 78% and 67%. Li and Zhang reported removals of 24-36% at two plants, while higher removals of 67.9-100% were reported by Karthikeyan and Meyer in four Taiwanese wastewater treatment plants. For tetracyclines, removal efficiency at Mzumbe wastewater treatment plant was incomplete, especially at Mzumbe wastewater treatment plant. Sulfonamides were removed relatively more efficiently compared to other studied antibiotics, especially at Mafisa wastewater treatment plant. As for the occurrence and removal of antibiotics from the two studied wastewater treatment plants, these were found to be within the range of other wastewater treatment plants. Probably antibiotics from studied wastewater treatment plants are sources of water bodies like rivers contamination in Morogoro municipality.

6. Conclusion

All the selected antibiotics were found in the influents and effluents at two studied wastewater treatment plants. The highest level of total antibiotics was found in Mafisa wastewater treatment plant, which receives wastewater from large population inhabiting the morogoro municipality, compare to at Mzumbe wastewater treatment plant which receives wastewater mainly from a small population of Mzumbe University community.

The removal of antibiotics by the two wastewater treatment plants was incomplete, especially at Mzumbe wastewater treatment plant. Sulfonamides were removed relatively more efficiently compared to other studied antibiotics, especially at Mafisa wastewater treatment plant. As for the occurrence and removal of antibiotics from the two studied wastewater treatment plants, these were found to be within the range of other wastewater treatment plants. Probably antibiotics from studied wastewater treatment plants are sources of water bodies like rivers contamination in Morogoro municipality.

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