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Occurrence, distribution, and ecotoxicological risk assessment of selected pharmaceutical compounds in water from Lake Victoria, Uganda

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Keywords:

Pharmaceuticals, Risk assessment, Lake Victoria, Surface water, East Africa

High lights:

- First findings of pharmaceutical residues in Africa´s largest fresh water lake
- 24 pharmaceuticals were determined in water from Lake Victoria, Uganda
- 18 were quantifiable at concentrations of ng L^{-1}
- Sulfamethoxazole, trimethoprim, ibuprofen, and diclofenac were most predominant
- Ecotoxicological risk assessment showed high, medium, and low risks

Abstract

The occurrence of 24 pharmaceuticals (including; 15 antibiotics, three analgesic/anti-inflammatory drugs, three anti-epileptic/ antidepressant drugs, two beta blockers, and one lipid regulator) was investigated in 75 water samples collected from four bays in the Ugandan part of Lake Victoria. In addition, the potential environmental risk of the target pharmaceutical compounds to aquatic organisms in the aquatic ecosystem of Lake Victoria was assessed. Water samples were extracted using solid phase extraction and analyzed for pharmaceuticals using high- performance liquid chromatography coupled with triple quadrupole mass spectrometry (LC/MS/MS). Eighteen of the 24 pharmaceuticals occurred at quantifiable concentrations. Sulfamethoxazole (1-5600 ng L^{-1}), trimethoprim (1-89 ng L^{-1}), tetracycline (3-70 ng L^{-1}), sulfacetamide (1-13 ng L^{-1}), and ibuprofen (6-780 ng L^{-1}) occurred at quantifiable concentrations in all water samples. Sulfamethazine (2-50 ng L^{-1}), erythromycin (10-66 ng L^{-1}), diclofenac (2-160 ng L^{-1}), and carbamazepine (5-72 ng L^{-1}) were only quantifiable in water samples from Murchison Bay. The highest concentrations of pharmaceuticals were found in Murchison Bay, the main recipient of sewage effluents, industrial and municipal waste from Kampala city via the Nakivubo channel. Ecotoxicological risk assessment showed that sulfamethoxazole, oxytetracycline, erythromycin, and diclofenac pose a high toxic risk to aquatic organisms in the lake, while ciprofloxacin, norfloxacin, and ibuprofen pose a medium risk. This study is the first of its kind to report the levels and ecotoxic risks of pharmaceutical compounds in Lake Victoria waters, of Uganda, and East Africa as a whole.

1. Introduction

The occurrence of pharmaceuticals in the aquatic environment is attracting much concern across the world (Heberer, 2002; Hughes, et al., 2013; Kümmerer, 2009), due to their potentially adverse effects on the aquatic environment (Ebele et al., 2017; Kümmerer, 2003). Pharmaceuticals are associated with many adverse effects in aquatic ecosystems including; endocrine disrupting effects on fish (Daughton and Ternes, 1999), antibacterial resistance development (Kümmerer, 2004; Mulla et al., 2018; Sandegren, 2019; Su et al., 2016), and inhibition of cell proliferation in aquatic organisms, affecting their physiology and morphology (Pomati et al., 2006). Some pharmaceutical compounds also have the potential to accumulate in the food web (Ebele et al., 2017; Ramirez et al., 2009). Pharmaceuticals used for the treatment of humans enter the aquatic environment primarily through municipal wastewater treatment plant (WWTP) discharges (studies have shown incomplete elimination for most pharmaceuticals in conventional WWTPs; Subedi and Loganathan, 2016; Verlicchi et al., 2012; Ying et al., 2009), directly if there is no sewage treatment, by disposal of unused or expired drugs in the drain or toilet, municipal and domestic waste, industrial effluents, and from veterinary sources via manure application (Ellis, 2006; Kolpin et al., 2002; Kümmerer, 2001).

Pharmaceutical residues have been found in surface and ground waters across the world (Heberer, 2002; Rodil et al., 2012; Kolpin et al., 2002; Padhye et al., 2014; Wang et al., 2011; Bu et al., 2013). However, very little information is available concerning the presence of pharmaceutical compounds in African aquatic environments (Hughes et al., 2013; Sorensen et al., 2015). In particular, the occurrence and probable sources of pharmaceuticals in the Lake Victoria waters of Uganda are unknown. This challenge is aggravated by the fact that the use of pharmaceuticals, particularly antibiotics, in Uganda has been increasing steadily over the last decades attributed to a high burden of infectious diseases (UNAS et al., 2015). Accordingly, high amounts of antibiotics are used in treating bacterial infections especially in immunosuppressed patients (mostly HIV/AIDs infected patients) and children below five years of age (UNAS et al., 2015). In addition, there is increasing use of antibiotics in poultry and livestock (Groot and van't Hooft, 2016; Kümmerer, 2004; UNAS et al., 2015). There is also an extensive availability of antibiotics "over the counter" without prescription (UNAS et al., 2015). Together, these may result in high input into Lake Victoria and a potential threat to surface and groundwater quality.

Lake Victoria, the second largest freshwater lake in the world and Africa's largest, is a very important natural aquatic resource in Uganda and East Africa for fish and both domestic and industrial water. However, the lake's ecological health is damaged largely by increased industrial, urban, and agricultural activities in its basin via polluted runoffs. In Uganda, Lake Victoria is particularly threatened as the major recipient for domestic and industrial wastewater, which has greatly affected the water quality of the lake ecosystem. In recent studies, the concentrations of persistent organic pollutants (POPs) such as DDT, dieldrin, aldrin, endrin, chlordane, PCDD/Fs, PCBs, PBDEs, and HCHs in Lake Victoria have been documented (Ssebugere et al., 2014; Wasswa et al., 2011). However, a survey of literature shows no available data concerning the concentrations of pharmaceutical residues in Lake Victoria.

This study investigated the occurrence and possible ecotoxic effects of various classes of commonly-used human and veterinary pharmaceuticals including, 15 antibiotics (three sulphonamides, two tetracyclines, three macrolides, five fluoroquinolones, one diaminopyrimidine and one nitroimidazole), three analgesic/anti-inflammatory drugs, three anti-epileptic/ antidepressant drugs, two beta blockers and one lipid regulator (Table 1) in water from Lake Victoria, Uganda.

2. Materials and Methods

2.1. Selection of target compounds

Target analytes were selected mainly based on a survey carried out at the beginning of this study. The survey identified the pharmaceutical products that are commonly sold in pharmacies and drug shops located in areas surrounding Lake Victoria. The survey also involved identifying the antibiotics that are commonly used in most medical centres and those that are extensively used in animal husbandry (poultry and cattle). In addition, other compounds were selected on the basis of their frequency of detection in fresh waters elsewhere (Hughes et al., 2013; Kolpin et al., 2002; Padhye et al., 2014; Wang et al., 2011). Selected target analytes and their respective internal standards are presented in Table 1.

Table 1. Target analytes and respective internal standards used for their quantification.

Compound	Class	CAS. No.	Molecular formula	Molecular mass (g/mol)	Internal standard
	Antibiotics				
Trimethoprim	Diaminopyrimidine	738-70-5	$C_{14}H_{18}N_4O_3$	290.3	Trimethoprim-d_3
Sulfamethoxazole	Sulphonamides	723-46-6	$C_{10}H_{11}N_3O_3S$	253.3	Sulfamethoxazole-d_4
Sulfamethazine		57-68-1	$C_{12}H_{14}N_4O_2S$	278.3	Sulfamethoxazole-d_4
Sulfacetamide		144-80-9	$C_8H_{10}N_2O_3S$	214.2	Sulfamethoxazole-d_4
Oxytetracycline	Tetracyclines	2058-46-0	$C_{22}H_{24}N_2O_9$	460.4	Thiabendazole-d_4
Tetracycline		64-75-5	$C_{22}H_{24}N_2O_8$	444.4	Thiabendazole-d_4
Erythromycin	Macrolides	114-07-8	$C_{37}H_{67}NO_{13}$	733.9	Erythromycin-^{13}C-d_3
Azithromycin		117772-70-0	$C_{38}H_{72}N_2O_{12} \cdot 2H_2O$	785.0	Erythromycin-^{13}C-d_3
Roxithromycin		80214-83-1	$C_{41}H_{76}N_2O_{15}$	837.1	Erythromycin-^{13}C-d_3
Ciprofloxacin	Fluoroquinolones	93107-08-5	$C_{17}H_{18}FN_3O_3 \cdot HCl$	367.8	Ciprofloxacin-d_8
Levofloxacin		100986-85-4	$C_{18}H_{20}FN_3O_4$	361.4	Ciprofloxacin-d_8
Norfloxacin		70458-96-7	$C_{16}H_{18}FN_3O_3$	319.3	Ciprofloxacin-d_8
Sparfloxacin		110871-86-8	$C_{19}H_{22}F_2N_4O_3$	392.4	Ciprofloxacin-d_8
Enoxacin		74011-58-8	$C_{15}H_{17}FN_4O_3$	320.3	Ciprofloxacin-d_8
Metronidazole	Nitroimidazole	443-48-1	$C_6H_9N_3O_3$	171.2	Thiabendazole-d_4
Ibuprofen	**Analgesic/ anti-inflammatory**	239-784-6	$C_{13}H_{18}O_2$	206.3	Ibuprofen-d_3
Diclofenac		15307-86-5	$C_{14}H_{11}Cl_2NO_2$	296.2	Diclofenac-d_4
Acetaminophen		103-90-2	$C_8H_9NO_2$	151.2	Ibuprofen-d_3
Carbamazepine	**Antiepileptics/ Antidepressant**	298-46-4	$C_{15}H_{12}N_2O$	236.3	Carbamazepine-d_{10}
Diazepam		439-14-5	$C_{16}H_{13}ClN_2O$	284.7	Carbamazepine-d_{10}
Fluoxetine		56296-78-7	$C_{17}H_{18}F_3NO.HCl$	345.8	Fluoxetine-d5
Atenolol	**Beta-Blockers**	29122-68-7	$C_{14}H_{22}N_2O_3$	266.3	Atenolol-d_7
Metoprolol		56392-17-7	$(C_{15}H_{25}NO_3)2 \cdot C_4H_6O_6$	684.8	Atenolol-d_7
Bezafibrate	**Lipid regulators**	41859-67-0	$C_{19}H_{20}ClNO_4$	361.8	Fluoxetine-d5

2.2. Standards and reagents

All reference and isotope-labelled internal standards in their crystalline form were purchased from Dr. Ehrenstorfer GmbH (Augsburg, Germany) with the exception of Thiabendazole-d_4, Erythromycin-^{13}C-d_3, rac Ibuprofen-d_3 and Fluoxetine-d_5 hydrochloride which were obtained from Toronto Research Chemicals Inc. (North York, Ontario, Canada). Chromabond HR-X solid phase extraction (SPE) cartridges were purchased from Macherey-Nagel GmbH & Co. KG (Düren, Germany). Methanol and acetonitrile solvents (HPLC-gradient grade) were obtained from VWR international BDH Prolabo Chemicals (Darmatadt, Germany). Formic acid, methyl tertiary-butyl ether solvent (HPLC-gradient grade) and disodium ethylenediamine tetraacetate (Na_2EDTA, Analytical grade) were purchased from Merck KGaA (Darmstadt, Germany). The nitrogen gas (99.5%) was obtained from a nitrogen (Air Products GmbH, Hattingen, Germany). Water was purified by SG Ultra clear UV plus TM water purification system (SG Water Treatment and Regeneration GmbH, Günzburg, Germany). All standard stock solutions were prepared in methanol at a concentration of 1000 mg/L, except for fluoroquinolone antibiotics which were prepared in methanol containing 1% 1 M sodium hydroxide.

2.3. Study area

The study area was the Ugandan sector of Lake Victoria (Fig. 1). Lake Victoria covers a surface area of about 68 800 km^2 shared across three East African countries; Uganda (45%), Kenya (6%) and Tanzania (49%) with a catchment area of 193 000 km^2. The lake stretches 412 km across the equator between latitudes 0˚30' N - 3˚12' S, and 355 km between longitudes 31˚37'W - 34˚53' E. The catchment area of the lake on the Uganda side has experienced rapid ecological changes as a result agricultural practices that have led to massive deforestation. Because of increasing human settlements, the lake shores, which were historically surrounded by extensive papyrus-dominated wetlands, have been degraded resulting in increased sedimentation and water pollution (Wasswa et al., 2011). Four bays; Murchison Bay, Waiya Bay, Napoleon Gulf and Thurston Bay (Fig. 1) were selected as appropriate sites for the study due to dense human habitation, wide range of industrial and commercial activities as well as increased agricultural activities within their immediate localities. A detailed description of the study bays is provided in the supplementary information (Text S1)

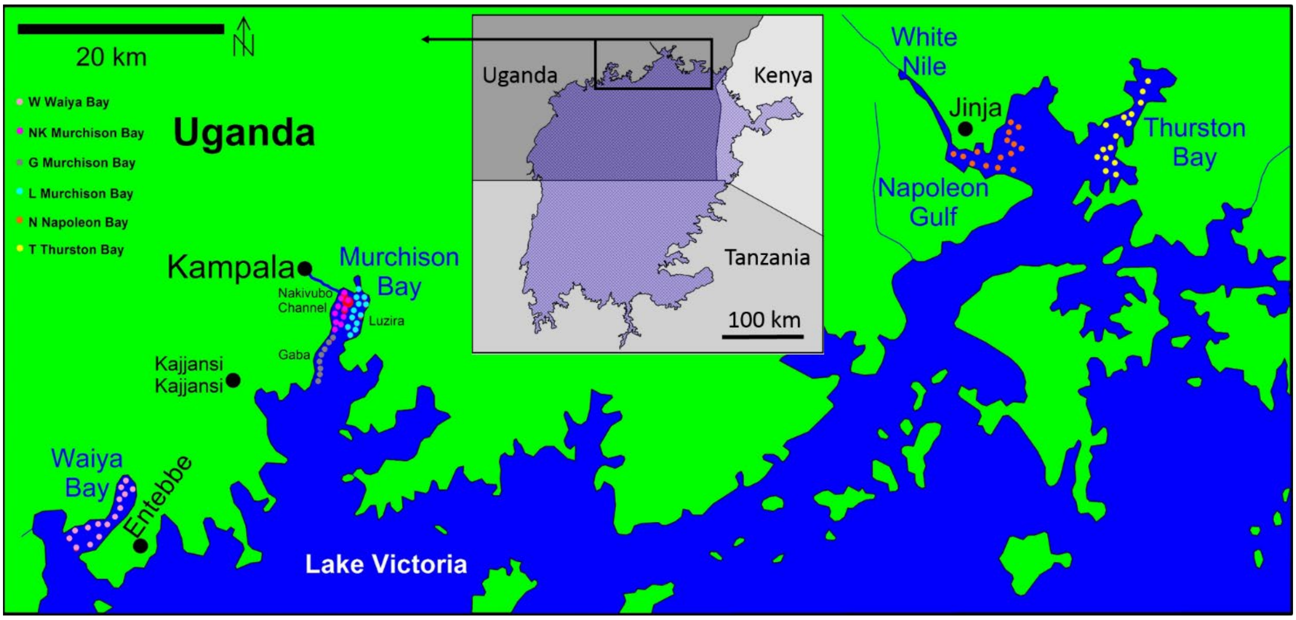

Fig. 1. Map of Lake Victoria showing the location of the bays and sampling regions (coloured dots). Blue indicates water, and green indicates land

2.4. Sample collection

Seventy-five surface water samples were collected in amber glass bottles (Murchison Bay 30 samples, Waiya Bay 15 samples, Napoleon Gulf 15 samples, and Thurston Bay 15 samples) (Fig. 1) in the months July to September 2018. Details of population density and industrial and economic activities within the catchment of each bay is provided in Text S1 (Supplementary information). The exact location of the sampling points is described in Table S1, while some features around the sampling bays are provided in Table S2. On-site water quality parameters were determined and the samples were immediately stored in an iced cool box for transportation to the laboratory. In the laboratory, all water samples were solid-phase extracted within 48 hours from the time of collection. Within a week after extraction, the enriched SPE cartridges were couriered to Lüneburg, Germany for further analysis.

2.5. Water quality characterization

Temperature, pH, conductivity, turbidity, and total dissolved solids (TDS) were determined for all the water samples (Table S3) to assess their degree of association with concentrations of pharmaceuticals.

2.6. Solid phase extraction of samples

Solid phase extraction of water samples was performed according to US EPA method 1694 (U.S. EPA, 2007), with modification and validation (Wang et al., 2011). Water samples (1 L) were filtered through a Whatman GF-C glass fiber filter and the filtrate was acidified to pH 2-2.5 using 1 M sulphuric acid. This was followed by the addition of Na_2EDTA (0.5 g) to chelate the metal cations and 1 mg/L internal standards mixture (50 µL). The samples were mixed thoroughly and left to stand for 10 min after which they were extracted using 3 mL (200 mg) Chromabond HR-X extraction cartridges pre-conditioned with 9 mL of methanol followed by 9 mL of Milli-Q water at a flow rate of 3 mL/min. The samples were passed through the SPE cartridges at a flow rate of 8 mL/min. After extraction of the sample, each cartridge was washed with 6 mL of Milli-Q water to remove any residues of Na_2EDTA. The enriched cartridges were then dried with a gentle stream of nitrogen for 30 minutes. The analytes on the cartridges were then eluted sequentially with 6 mL of methanol, 3 mL of methanol-methyl tertiary-butyl ether (1:1) mixture and 3 mL of methanol with 1% formic acid (v/v) at a flow rate of 1 mL/min. The eluate was concentrated under a gentle stream of nitrogen to approximately 200 µL and quantitatively transferred to 500 µL final volume with methanol containing 0.1% formic acid (v/v) in a 1.5-mL amber glass sample vials. Finally, extracts were stored in a refrigerator at - 4 ºC for not more than 8 hours until LC-MS/MS analysis.

2.7 LC-MS/MS analysis

The separation of analytes was performed using an Agilent 1200 series HPLC system (Agilent Technologies, Inc., Santa Clara, CA, USA), on an Agilent Poroshell 120 EC-C18 column (2.1 × 50 mm,1.9 µm) (Agilent Technologies, Inc., Santa Clara, CA, USA). The mobile phase was made up of a binary gradient between acetonitrile, and water with 0.1% formic acid (v/v). Before starting each analysis, there was a 5 minutes equilibration of the column at 15% acetonitrile. The mobile phase gradient was ramped at a flow rate of 0.4 mL/min starting from 15% acetonitrile (held for 3 min) to 50% acetonitrile in 2 minutes (held for 2 min), then ramped to 80% acetonitrile in 3 min and finally to 15% acetonitrile in 3 min (held for 2 min). The injection volume for each sample was 5 µL whereas the column temperature was set at 25 °C.

Mass spectrometric analysis of the target compounds was carried out using Agilent 6430 triple quadrupole mass spectrometer (Agilent Technologies, Inc., Santa Clara, CA, USA) equipped with an electrospray ionization source in both positive (ESI^+) and negative (ESI^-) modes. The nebulizer pressure was set to 50 psi and the capillary voltages were 4000 V. The temperature and flow rate of drying gas were set at 325 °C and 8 L/min respectively. Compound dependent mass spectrometer parameters were optimized for each of analyte. After optimization, the ion transition with the highest abundance was selected as the quantification ion pair (quantifier) for the corresponding compound, while the ion transition with the second highest abundance was selected as the confirmation ion pair (qualifier) for the corresponding compound. Sample acquisition was performed in the multiple reaction monitoring (MRM) mode. Quantification of target compounds was performed using MassHunter software (Version B.08.02 Build 8.2.8260.0 from 2017/02/17 Agilent Technologies, Inc. 2017, Santa Clara, CA, USA).

2.8 Quality control

Quantification of each analyte was carried out on a 10-point calibration curve in the range of 1 ug L^{-1} to 1000 ug L^{-1} using the internal standard quantitation method. Selected isotope-labeled internal standards (Table 1) were spiked at 100 ng L^{-1} into the samples prior to SPE and used for quantification of their corresponding target compounds. Most of the target compounds had available deuterated counterparts except a few for which the internal standards were selected among those available based on their properties and chemical structures. For every batch of water samples analyzed, one procedural blank (1 L of ultrapure milli-Q water), two blank spike recoveries (1 L of ultrapure milli-Q water spiked with the target analytes at known concentrations of 50 ng $L^{-1}$and 100 ng L^{-1}), and two spike recovery samples (Actual water samples spiked with the target compounds at known concentrations of 50 ng $L^{-1}$and 100 ng L^{-1}) were included to check the potential for background contamination, recovery and method performance. Recoveries of the pharmaceuticals were determined at the two spiking concentration levels (50 and 100 ng L^{-1}), and calculated as the percentages of the measured concentrations relative to the spiked concentrations. The method detection limit (LOD) and quantification limit (LOQ) were calculated as described in the guidelines of the Germany Institute for Standardization (DIN 32645) (Kolb et al., 1993). Intra-day and inter-day precision were determined from six repeated analysis during the same day (repeatability) and in six successive days (reproducibility) and the two precision parameters were expressed as the relative standard deviation (RSD, %).

2.9 Statistical data analysis

Summary statistics and comparisons were performed using GraphPad Prism 8.1.0 software (www.graphpad.com). Normality of data was tested using the D'Agostino-Pearson test. Non-parametric statistical tests were applied, since in many cases, the data was not normally distributed. The Kruskal-Wallis test was used to compare concentrations of the same compound between bays, followed by the Dunnett's T3 for multiple comparisons. Statistical significance was set at $p < 0.05$ for all the tests.

Linear regressions were done with temperature, pH, conductivity, turbidity, alkalinity, hardness, and total dissolved solids (TDS), also using Prism. This was done to assess the degree of association between the water quality parameters and concentrations of pharmaceuticals. Linear regression adjusts the slope and intercept of a line that best predicts concentration from a continuous variable. More precisely, the goal of regression is to minimize the sum of the squares of the vertical distances of the points from the line. For goodness-of-fit, we report both r^2 and the standard deviation of residuals (*Sy.x*).

Multivariate statistics was done using MjM Software PC-ORD version 7.03 (www.pcord.com) to compare the relative compositions of the pharmaceuticals of each bay. This was done by means of non-metric multidimensional scaling (NMS) of relativized data. NMS avoids the assumption of linear relationships between variables (in this case, probable covariance of related compounds such as the antibiotics) using ranked distances to linearize the relationships between measured distances in ordination space. To investigate the compound profiles of each sample with all other samples, the concentrations were relativized per compound across all samples. This provides a 'fingerprint' based on the relative compound composition of each sample rather than absolute values. Each sample's relative composition can now be compared with every other, irrespective of absolute concentrations, using NMS. A maximum of six dimensions and 500 iterations were allowed from random starting conditions, using 250 runs of real data. When the standard deviation of the stress of at least ten runs reached <0.0001, a stable ordination was assumed, whereupon Monte Carlo tests were done with 250 runs of randomised data. Convex hulls for each bay were drawn to assess congruence (overlap) of proportional contributions ('fingerprints') of the analysed compounds. Flexible Beta (0.25) was used as a group linkage method for hierarchical cluster analyses of absolute values, with Gower-ignore-0 as distance measure.

2.10 Ecotoxicological risk assessment

The potential ecotoxic risk of the target pharmaceutical compounds to aquatic organisms in the ecosystem of Lake Victoria was assessed based on risk quotients (RQs), following the European Commission's Technical Guidance Document on risk assessment (European Commission, 2003). Risk quotients of individual pharmaceutical compounds were calculated as the ratio of their maximum measured environment concentration (MEC) to their Predicted No Effect Concentrations (RQ = MEC/PNEC). Predicted No Effect Concentrations (PNECs), which are the concentrations for which adverse effects are not expected to occur for these substances (European Commission, 2003) were derived from chronic and acute toxicity data available in the literature (see Table S4 of the supplementary information). The PNECs were calculated by dividing the lowest chronic No Observed Effect Concentration (NOEC) or acute $E(L)C_{50}$ values (concentrations causing 50% death or effect) for the most sensitive indicator species (Table S4) by the appropriate assessment factor (European Commission, 2003). For detected pharmaceutical compounds where NOEC values for species representing only one trophic level (*Daphnia* or fish) were available, an assessment factor 100 was used for PNEC calculations. Assessment factors 50 and 10 were used when NOEC values were available for species representing two trophic levels (fish, and/or *Daphnia*, and/or algae) and three trophic levels (usually fish, *Daphnia*, and algae) respectively. In addition, an assessment factor of 1000 was used for acute toxicity data (European Commission, 2003). The NOECs and assessment factors used for the calculation of PNECs are presented in Table S5. RQs were calculated based on the worst-case scenario, by considering maximum concentrations detected, as well as the lowest NOECs or E(L)C50. In this study, a frequently used risk ranking criteria described by Hernando et al., (2006) was applied: $RQ < 0.1$, minimal risk; $0.1 \leq RQ < 1$, median risk; and $RQ \geq 1$, high risk. The risk posed by a mixture of 18 detected pharmaceuticals was also calculated using the concentration addition model. The normal equation used for concentration addition is $TT = \sum Ci/Ti$, where TT is the total toxicity of the mixture, C is the concentration of pharmaceutical i, and Ti is a measure of the toxicity of pharmaceutical i, such as the LC_{50}/EC_{50}. In this study, a modified equation for concentration addition was used where Ci/Ti was replaced by RQi according to Zhao et al., (2009).

3. Results and Discussion

3.1. LC-MS/MS detection

All target compounds were optimized individually in both ESI^+ and ESI^- modes. Higher abundances of ion transitions were obtained in the ESI^+ than in the ESI^- mode for all the target compounds. Therefore, all the target compounds were analysed in the ESI^+ mode. The optimum mass spectrometry compound-dependant parameters for the target analytes and internal standards including precursor ion, product ions, fragmentor voltage and collision energy are listed in Table S6. All the target compounds were analysed in the multiple reaction monitoring (MRM) mode. The optimized LC/MS/MS parameters including; precursor ion, product ions, fragmentor voltage, and collision energy (CE) for target analytes and internal standards are presented in the supplementary information (Table S6).

3.2 Quality control and quality assurance

The method was validated for each analyte in terms of recovery, precision, limit of detection (LOD) and limit of quantification limit (LOQ). Satisfactory recoveries were obtained for most of the target pharmaceutical compounds at the two spiking concentration levels (50 and 100 ng L^{-1}) for both spiked blanks and spiked matrices ranging between 70% to 121% (Table S7). However, some compounds, such as metronidazole, sulfacetamide, acetaminophen, and enoxacin, had low recovery of both spiked blanks and spiked matrices, ranging between 51-70%. The precision of the method, estimated as relative standard deviation, varied in the range from 0.2 to 15% for all the compounds. Linearity was observed in the concentration range studied (1 ug L^{-1} to 1000 ug L^{-1}) with the coefficients of correlation greater than 0.994 for all the pharmaceuticals analysed (Table S7). The method limits of detection (LOD) and quantification (LOQ) for the target analytes are also summarized in Table S7. Sulfacetamide, Tetracycline, Erythromycin, Levofloxacin and Sparfloxacin showed the lowest LOD (0.2 ng L^{-1}) whereas enoxacin and oxytetracycline showed the highest LOQ of 15 ng L^{-1} and 13 ng L^{-1} respectively.

3.3 Concentrations of pharmaceuticals in water from Lake Victoria, Uganda.

The range and median concentrations of pharmaceuticals in water samples (n=75) from Lake Victoria are presented in Table 2.

Table 2: Ranges and median concentrations (ng L^{-1}) of selected pharmaceuticals in water from Lake Victoria, Uganda.

Analyte	Abbreviation	Frequency of detection (%)	Minimum	Maximum	Median
Trimethoprim	Trim	100	1.1	89	11
Sulfamethoxazole	SulfO	100	0.8	5600	5.8
Sulfamethazine	Sulfl	40	2.4	50	7.8
Sulfacetamide	SulfA	100	0.8	13	3.1
Oxytetracycline	Oxyt	88	17	300	82
Tetracycline	Tetra	100	2.7	70	9.5
Erythromycin	Eryth	16	10	66	37
Azithromycin	Azith	20	14	60	16
Ciprofloxacin	Cipro	91	2.0	41	15
Levofloxacin	Levo	96	1.8	29	13
Norfloxacin	Norfl	99	1.9	26	14
Enoxacin	Enox	88	5.9	51	25
Ibuprofen	Ibup	100	5.9	780	45
Diclofenac	Diclof	40	1.8	160	16
Acetaminophen	Acetam	72	1.6	27	6.2
Carbamazepine	Carbam	40	4.8	72	16
Atenolol	Aten	80	24	380	85
Metoprolol	Metop	95	0.4	21	3.4

Out of the twenty-four targeted pharmaceutical compounds, eighteen were detected at quantifiable concentrations, including; twelve antibiotics, three analgesic/anti-inflammatory drugs, one anti-epileptic/antidepressant drugs, and two beta blockers (Table 2). The antibiotics sulfamethoxazole (1-5600 ng L^{-1}), trimethoprim (1.1-89 ng L^{-1}), tetracycline (2.7-70 ng L^{-1}), and sulfacetamide (1-13 ng L^{-1}), and the analgesics/anti-inflammatory drug ibuprofen (6-780 ng L^{-1}) were quantified in all the water samples analysed (100% detection frequency). The high frequency of detection for sulfamethoxazole and trimethoprim may be due to the widespread use of trimethoprim-sulfamethoxazole prophylaxis among HIV-infected patients in Uganda (Ogwang et al., 2015). The frequency of detection of tetracycline may be a result of its extensive use in poultry and cattle farming in the areas around the lake (Bashahun & Odoch, 2015). Ciprofloxacin (2.0-41 ng L^{-1}), levofloxacin (1.8-29 ng L^{-1}) and norfloxacin (1.9-29 ng L^{-1}) were also frequently detected probably due to their frequent prescription in pharmacies and medical centers (Kiguba et al., 2016). Results shows that among all the targeted pharmaceutical compounds, sulfamethoxazole (1-5600 ng L^{-1}) had the highest concentrations, followed by ibuprofen (6-780 ng L^{-1}), atenolol (24-380 ng L^{-1}), oxytetracycline (17-300 ng L^{-1}), diclofenac (1.8-160 ng L^{-1}), trimethoprim (1.1-89 ng L^{-1}), carbamazepine (4.8-72 ng L^{-1}) and tetracycline (2.7-70 ng L^{-1}). The high concentration of sulfamethoxazole was possibly due to its high stability and long-term persistence in the aquatic ecosystem (Mulla et al., 2018), in addition to its extensive use in Uganda. Sulfacetamide (1-13 ng L^{-1}) and metoprolol (0.4-21 ng L^{-1}) had the lowest concentrations. Carbamazepine (4.8-72 ng L^{-1}) was the only antidepressant/antiepileptic drug detected. Pharmaceutical residues in Lake Victoria represent a variety of origins including; municipal waste, run off from agricultural farms (poultry, cattle, and fish), effluents from pharmaceutical industries, and from WWTPs draining into the lake. Contamination of surface water in Lake Victoria with pharmaceuticals is also attributed to extensive use and medication without prescription combined with inappropriate disposal of used and expired pharmaceuticals in human medicine and agriculture.

The most prominent class of pharmaceuticals occurring at quantifiable concentrations were the antibiotics, having detected 12 antibiotics out of the 15 analysed. The occurrence of antibiotics in Lake Victoria is of concern due to their potential to induce antibiotic resistance in pathogenic bacteria (Kümmerer, 2004; Su et al., 2016). Resistant bacterial strains may cause bacterial infections that cannot be treated by antibiotics (Khachatourians, 1998) anymore, especially if several or many strains become resistant against them. Recent research has shown that even low concentrations found in many aquatic environments contaminated with antibiotics from anthropogenic sources can select for resistant bacteria (Sandegren, 2019). Therefore, the antibiotic resistance reported in Uganda according to UNAS et al. (2015) may be attributed to the occurrence of antibiotics in the aquatic environment of Lake Victoria, since it is the major source of water for both domestic and industrial use in the region.

Generally, the concentrations of sulfamethoxazole, oxytetracycline, erythromycin, diclofenac, and carbamazepine in the present study were higher than in freshwater bodies from other regions (Table S8). The markedly higher concentrations of sulfamethoxazole residues in Lake Victoria are possibly due to its extensive use in Uganda particularly in immunosuppressed patients while high concentrations of oxytetracycline are probably due to its wide application in poultry and livestock (UNAS et al., 2015). The concentrations of trimethoprim in Lake Victoria water were higher than those found in the Ebro River, Spain, as well as in several major USA rivers (Conley, Symes, Schorr, & Richards, 2008; Padhye et al., 2014; Silva et al., 2011). The relatively high concentration of trimethoprim in Lake Victoria may be attributed to its wide use among people living with HIV. The concentrations of ciprofloxacin were higher than those registered in US streams but lower than those found in the Kisat and Sosian rivers in Kenya (Kimosop, Getenga, Orata, Okello, & Cheruiyot, 2016). The concentrations of sulfamethazine, sulfacetamide, azithromycin, tetracycline, levofloxacin and norfloxacin, and ibuprofen in Lake Victoria fall within the ranges reported for several surface waters in Europe (Rodil et al., 2009; Silva et al., 2011) and in the United States of America (Conley et al., 2008; Kolpin et al., 2002; Padhye et al., 2014; Wang et al., 2011). The concentration of acetaminophen was in the range of the values found in Mississippi and Tennessee Rivers, USA (Conley et al., 2008; Padhye et al., 2014; Wang et al., 2011). However, it was lower than the maximum concentrations found in Ebro River basin, Spain (Silva et al., 2011), and USA streams (Kolpin et al., 2002).

3.4 Distribution of pharmaceuticals in the sampling regions of Lake Victoria.

The concentrations of pharmaceuticals in water from the six sampling regions of Lake Victoria (Fig. 1) are presented Fig.2

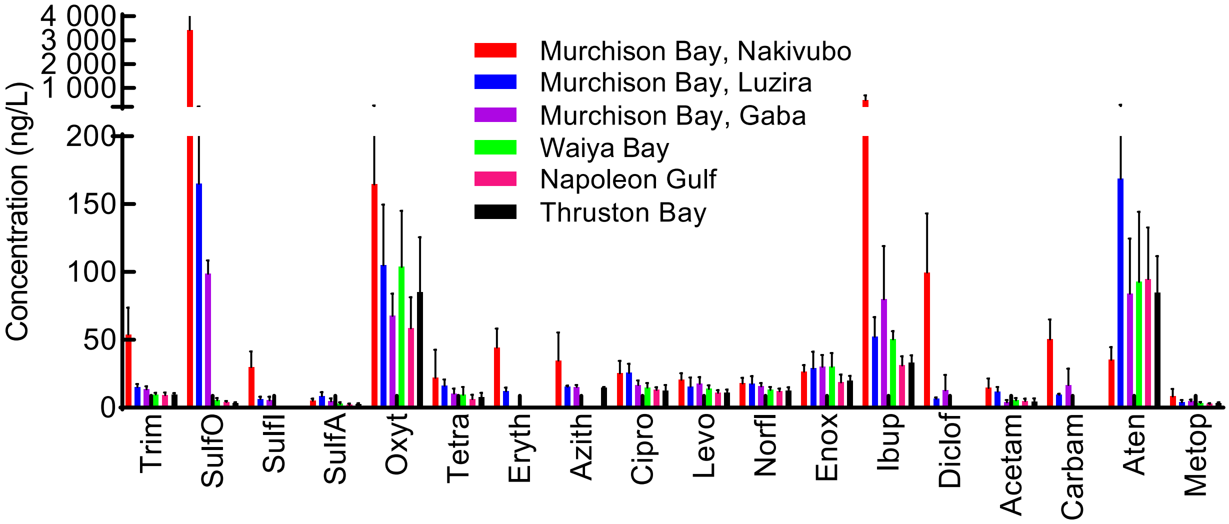

Fig. 2. Mean concentrations and standard deviations of pharmaceuticals in water, per sampling region. The abbreviations of the analytes are given in Table 2. Medians and ranges are given in Tables S9 and S10.

Eighteen compounds were detected in all the three Murchison Bay sampling regions, 14 compounds in Thurston Bay, and 13 compounds in Waiya Bay and Napoleon Gulf. From Table S9, the mean concentrations of pharmaceuticals in water from Lake Victoria ranged from 5.8 ng L^{-1} (metoprolol) to 1200 ng L^{-1} (sulfamethoxazole) in Murchison Bay, 2.9 ng L^{-1} (sulfacetamide) to 100 ng L^{-1} (oxytetracycline) in Waiya Bay, 2.3 ng L^{-1} (sulfacetamide) to 95 ng L^{-1} (Atenolol) in Napoleon Gulf, and 2.4 ng L^{-1} (sulfacetamide) to 85 (oxytetracycline) in Thurston Bay. Most of the target pharmaceutical compounds were detected in all the sampling regions with the exception of sulfamethazine, erythromycin, diclofenac, and carbamazepine which were detected in samples from Murchison Bay only. Murchison bay showed the highest concentrations of pharmaceuticals compared to other bays. Murchison bay was followed by Waiya Bay and then Napoleon Gulf, while Thurston Bay had the lowest concentrations. The mean concentrations of the different pharmaceutical compounds at the six sampling regions are shown in Fig. 2 and Fig S1. Results of the Kruskall-Wallis analyses are presented in Table S11.

Generally, the pharmaceutical concentrations in samples from Murchison Bay sampling regions were significantly higher ($p < 0.05$, Kruskal-Wallis) than those from Waiya Bay, Napoleon Gulf, and Thurston Bay (Table S11). In addition, the concentrations of sulfamethoxazole, oxytetracycline, levofloxacin, and ibuprofen in Waiya Bay were significantly higher ($p < 0.05$, Kruskal-Wallis) than those detected in Thurston Bay and Napoleon Gulf. However, the Kruskal-Wallis analyses between Napoleon Gulf and Thurston Bay showed no significant differences (Table S11).

Generally, there were high deviations from the mean concentrations of the different pharmaceutical compounds particularly sulfamethoxazole, oxytetracycline, ibuprofen, diclofenac, and atenolol in Murchison Bay as compared to all the other bays (Table S9 and Fig. 2). The high concentrations and the deviations in the concentrations of pharmaceuticals in Murchison Bay are attributed to point source contamination from the Nakivubo Channel into the Bay (Fig. 1). Murchison Bay is the main recipient of sewage effluents, pharmaceutical industrial waste, as well as municipal and hospital waste from Kampala City and its suburbs, through this channel. Prior to the last decade, Nakivubo channel was draining wastewater through papyrus swamps before entering Murchison Bay. However, the wetlands that played the role of secondary treatment have since been degraded due to economic and social pressures (Wasswa, 2011). In addition, Murchison Bay receives water effluents from two wastewater (sewage) treatment plants located in Bugolobi and Lubigi, which are nearby suburbs of Kampala. This is supported by the finding that samples collected from the mouth of the channel (Nakivubo region of Murchison Bay) showed significantly higher ($p < 0.05$, Kruskal-Wallis) concentrations of pharmaceuticals compared to those from Luzira and Gaba regions which are about 0.9 and 4 kilometres away from the channel respectively (Fig. 2 and Table S10). The variations in concentrations of pharmaceuticals within the same sub-region of Murchison bay may be a result of the different seasons during the sampling period. The antibiotic residues in water from Thurston Bay and Napoleon Bay are probably from fish farming (cage culture of fish) within the waters of the bays. Antibiotics are widely applied in fish farming to treat and or prevent bacterial infections (Kümmerer, 2004), where they are added directly to the water, resulting in high concentrations in the water compartment, adjoining sediments and fish (Coyne et al., 1994). These antibiotics residues may also be attributed to run off from poultry and cattle farms from the vicinities of the bays. The pharmaceutical residues in Waiya bay may be attributed to run off from commercial fish farms, poultry, and cattle farms as well as sewerage effluents from a wastewater treatment plant within the localities of the bay. In addition, the bay is situated close to a landing site where many commercial and domestic activities occur and could be releasing domestically-used pharmaceuticals into the lake.

3.5 Associations of pharmaceutical concentrations with water quality criteria

Water quality differed between the different sampling regions (Fig. 3).

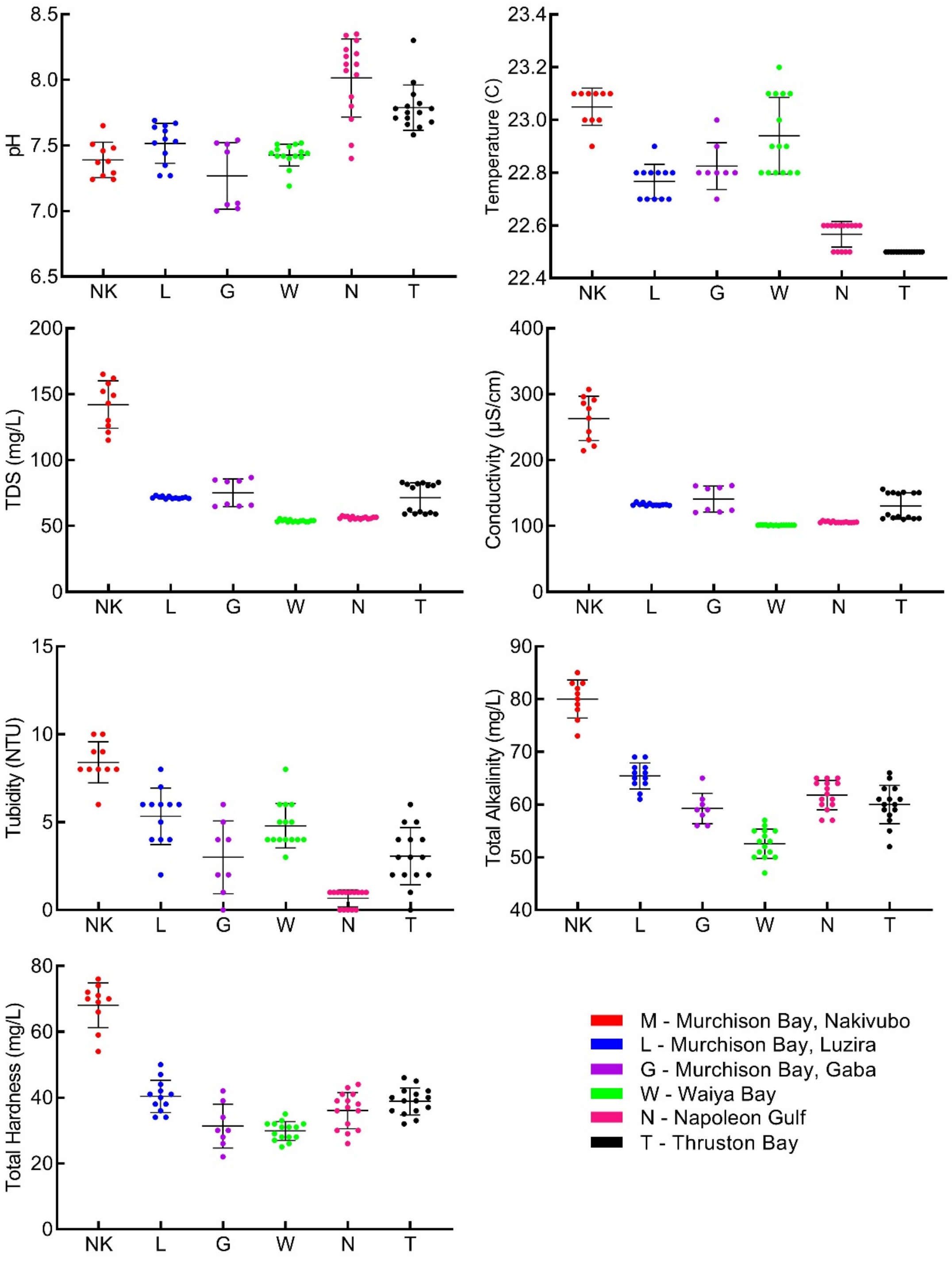

Figure 3: Water quality criteria of the different sampling regions of Lake Victoria, Uganda. Kruskal-Wallis analyses for all criteria were significant ($p<0.05$). For Dunn's multiple comparisons, see Table S13 in Supplementary information.

Regression analysis results for water quality data against concentrations of all compounds (Table S12) showed that almost all compounds were significantly linearly associated with the measured water quality parameters. The slopes indicated whether there is a positive or negative association between the pharmaceutical concentrations and the water quality variable. For pH, all slopes were negative, indicating that the greater the pH, the lower the concentration. However, for the rest of the water quality parameters (temperature, alkalinity, turbidity, conductivity, total dissolved solids, and hardness), the slopes were positive implying the greater the water quality parameter the higher the concentration of pharmaceutical compounds. Interestingly, even temperature had significant linear associations with 15 of the 18 compounds analyzed.

In all, 14 of the compounds were significantly associated with six or more of the seven water quality criteria (Table S12, bottom row). pH had the least number of compounds with significant association (12), temperature, alkalinity, and TDS predicted 15 compounds, turbidity was associated with 16 compounds, and conductivity and hardness were associated with 17 out of 18 compounds (Table S12 right-hand row). Not all regressions were as good, and r^2 and *Sy.x* should be consulted as to how well the points fitted the lines (Table S12).

The regression analyses showed that water quality criteria, normally associated with pollution and enrichment, were strongly associated with pharmaceutical concentrations in Lake Victoria water. It is clear, however, from Fig. 3 and Table S12, that the Nakivubo sampling region in Murchison Bay was the most contaminated. Generally, the higher concentrations of the measured pharmaceuticals were strongly associated with worst water quality, indicating that pollution from Kampala was the main contributor.

3.6 Multivariate analyses

Multivariate analyses can provide a single, visual representation of compound compositions per sample (equivalent to the ‘fingerprint’ of each sample) relative to all other samples, and with water quality measurements (Fig. 4). Only two dimensions were needed to ordinate the samples’ relative pharmaceutical composition (represented by the convex hulls) using NMS (see section 2.9). The final stress was 13.7, with a final instability of 0.0000, reached after 108 iterations. A final stress between 10 and 20 is considered as a satisfactory result, typical of ecological studies (McCune and Grace, 2002). Axis 1 explained 67.1%% of the variation, and axis 2 explained 23.3%, for a cumulative explanation of 90.4%. Overlap of the convex hulls indicates congruence of the ‘fingerprints’ or relative compositions per bay, while non-overlap shows differences or ‘uniqueness’**.**

The NMS ordination (Fig. 4) clearly shows that the relative pharmaceutical composition of Nakivubo samples was very different from all other sampling regions, and strongly associated with increased water quality parameters (temperature, alkalinity, turbidity, conductivity, total dissolved solids, and hardness) together with reducing water pH. The other two sampling regions of Murchison Bay (Luriza and Gaba), did not differ from each other in relative composition, but both differed from the other three bays. The three Murchison Bay sampling regions were strongly associated with higher relative compositions of diclofenac, erythromycin, sulfamethazine, and sulfamethoxazole, while the other three bays compositions were less dominated by these four.

Together with the higher concentrations of pharmaceuticals in the three sampling regions of Murchison Bay (Table S11), the strong associations of these concentrations with decreased water quality (Table S12), and the NMS visual representation, strongly suggest that pollution via the Nakivubo channel is responsible for the major part of the pollution in this bay. The other three bays may not receive pollution directly from this source, as their relative compositions differ, and they have generally lower concentrations and better water quality.

The NMS ordination plot (Fig.4) was confirmed by cluster analysis. The dendrogram in Fig. S2 (supplementary information) revealed two distinct clusters of the sampling sites: cluster A containing sites from Nakivubo, Murchison Bay and cluster B containing Luzira and the rest of the sampling sites. This implies that the relative pharmaceutical composition of Nakivubo sampling sites was far different from all other sampling regions and also that of Luzira is different from that of Gaba and the rest of the sampling sites. This is probably due to the in-flow of the Nakivubo channel, which is polluted by anthropogenic activities of Kampala City and its suburbs. The results suggested that Nakivubo sampling sites are more contaminated compared to Luzira, Gaba and the rest of the sampling sites. This is may be due to sedimentation and dilution factor as water moves away from the mouth of the Nakivubo channel. However, there are no major differences among Waiya, Napoleon and Thurston Bays.

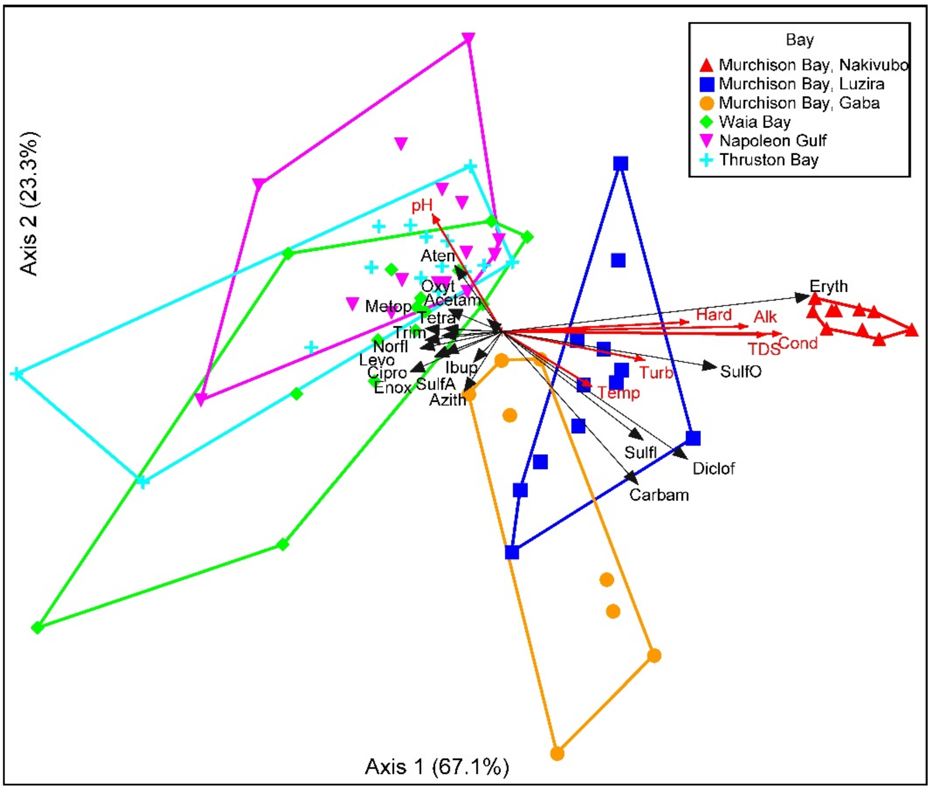

Fig. 4. Nonmetric multidimensional scaling (NMS) ordination plot for water quality parameters of samples and concentrations of all pharmaceutical compounds per bay.

3.7 Ecotoxicological risk assessment of pharmaceuticals in Lake Victoria

The risk of pharmaceuticals to aquatic organisms of Lake Victoria was assessed based on the risk quotients (RQs), according to the European technical guidance document on risk assessment (European Commission, 2003). The risk quotients of pharmaceuticals in the aquatic environment of Lake Victoria were calculated based on the worst-case scenario as a ratio of the maximum measured environmental concentration (MEC) to the predicted no-effect concentration (PNEC). The risk expressed as risk quotient (RQ) to aquatic organisms in Lake Victoria associated with the presence of the pharmaceuticals is displayed in Table 3. The risk assessment was based on the RQ classification scheme with three risk levels ($RQ < 0.1$ implies minimal risk, $0.1 \leq RQ < 1$ infers median risk and $RQ \geq 1$ indicates high risk) according to Hernando et al. (2006).

Table 3. Maximum measured environmental concentrations (MECs, ng L^{-1}), predicted no effect concentrations (PNECs, ng L^{-1}), and risk quotients (RQs) of individual pharmaceuticals in Lake Victoria

Compound	Maximum MEC	PNEC	RQ
Trimethoprim	89	31 0000	0.0003
Sulfamethoxazole	5 600	590	9.49
Sulfamethazine	50	15 630	0.003
Sulfacetamide	13	165 00 000	7.8E-07
Oxytetracycline	300	62	4.84
Tetracycline	70	20 000	0.004
Erythromycin	66	20	3.3
Azithromycin	60	120 000	0.0005
Ciprofloxacin	41	100	0.41
Levofloxacin	29	1 260	0.023
Norfloxacin	26	62	0.42
Enoxacin	51	248 900	0.0002
Ibuprofen	780	2 000	0.39
Diclofenac	160	50	3.2
Acetaminophen	27	6 000	0.005
Carbamazepine	72	2 500	0.03
Atenolol	380	20 000	0.02
Metoprolol	21	61 500	0.0003

RQ = MEC/PNEC [European Commission's Technical Guidance Document on risk assessment (European Commission, 2003)]

The RQ of sulfamethoxazole (9.5), oxytetracycline (4.8), erythromycin (3.3), and diclofenac (3.2) was greater 1 - an indication that they pose a high risk to aquatic organisms in the lake. This implied that these four pharmaceuticals were more harmful to non-target aquatic organisms (especially algae and invertebrates) in Lake Victoria when compared to the rest of the target pharmaceuticals. The risk posed by sulfamethoxazole may be attributed to its reported persistence and high biological activity against non-target organisms in the aquatic environment (Mulla et al., 2018) in addition to their extensive use. The RQs of ciprofloxacin (0.41) norfloxacin (0.42), and ibuprofen (0.39) were less than 1 but greater than 0.1, indicating that they pose a medium risk to the organisms in the aquatic environment of Lake Victoria. Trimethoprim, sulfamethazine, sulfacetamide, tetracycline, azithromycin, levofloxacin, enoxacin, acetaminophen, carbamazepine, atenolol, and metoprolol had RQs below 0.1, implying that they pose minimal risk and therefore unlikely to pose a threat to lives of aquatic organisms in the lake. A higher RQ of diclofenac (5.48) and a slightly lower RQ of ibuprofen (0.18) were obtained in Australia (Ying et al., 2009). Hernando et al., 2006 predicted high risks for diclofenac, ibuprofen, and carbamazepine in surface water. Diclofenac was also found to pose a high risk to aquatic organisms in River Kabul, Pakistan (Khan et al., 2018).

The total toxicity of a mixture of the 18 pharmaceuticals detected (RQ = 22.14) was also obtained. As expected, the ecotoxicological risk posed by the mixture was higher than that of the individual pharmaceutical compounds. This is attributed to the fact that pharmaceuticals with the same mechanism of action that do not interact should have additive toxicity that conforms to concentration addition (Kienzler et al., 2016; Thorpe et al., 2001; Warne and Hawker, 1995). This has also been supported experimentally (Pomati et al., 2006). However, little is known about the potential synergistic/antagonistic effects of mixtures of pharmaceuticals from different groups with a possibly different mode of action.

4. Conclusion

A total of 18 pharmaceuticals including, 12 antibiotics, three analgesic/anti-inflammatory drugs, one anti-epileptic/ antidepressant drug, two beta blockers and one lipid regulator were investigated in 75 water samples collected from bays of Lake Victoria, Uganda. Sulfamethoxazole, trimethoprim, and oxytetracycline were the most predominant antibiotics. Ibuprofen was the most detected analgesic/anti-inflammatory drug whereas atenolol was the most predominant beta-blocker found in water from Lake Victoria. Murchison Bay had the highest concentrations of pharmaceuticals of all the bays investigated, most likely due to inflow from the Nakivubo channel. Sulfamethoxazole, oxytetracycline, erythromycin, and diclofenac were the only pharmaceuticals with a risk quotient (RQ) greater than unity, suggesting that they pose a high toxic risk to aquatic organisms in the lake. Pharmaceuticals industrial wastewater discharge, wastewater effluents, municipal waste, and fish farms were probable sources of pharmaceuticals in Lake Victoria water. This study established Nakivubo channel as the main route of pharmaceutical contamination in Lake Victoria. This calls for a need to mitigate the inflows of the channel into the lake. Mitigating this inflow will most like improve both the water quality of Murchison Bay, and reduce the toxicity associated with pharmaceuticals. Additional research is also required to ascertain the photo- and biodegradation products of discrete pharmaceuticals in Lake Victoria. This will enable an improved understanding of their fate and transport in the aquatic ecosystem of the largest freshwater lake in Africa.

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SUPPLEMENTARY INFORMATION

Text S1: Description of the study bays

Murchison Bay, located 8 km south of Kampala City center is surrounded by the greater metropolitan Kampala area which is a hub of industrial and commercial activities (see Fig. 1 of the main manuscript). Kampala city is characterised by a high annual population growth rate of 5.6% and an estimated current population of about 2 million (Vermeiren et al. 2012). Murchison Bay covers a total area of about 62 km^2 between latitudes (00°10.00′ N – 00°30.00′ N) and longitudes (32°35.00′ E – 32°50.00′ E). Murchison bay is the abstraction point for the potable water supply for Kampala and the main recipient for surface runoff, sewage effluents, industrial- and municipal-waste from Kampala City, via the Nakivubo channel (Ssebugere et al., 2014). The channel passes through dense residential settlements, commercial and industrial areas. In the past, the channel ended in wetland areas, allowing wastewater to be drained into papyrus swamps before entering the Bay. However, in recent years the wetlands which played the role of secondary treatment have been degraded due to settlement and commercial activities (Wasswa, 2009). Samples from this bay were collected from three regions namely; Nakivubo located around the mouth of the channel and designated as NK1-10, Luzira located about 0.9 km from Nakivubo channel designated as L1-12 and Gaba located about 4 km from the channel designated as G1-8 (see Fig. 1 of the main manuscript).

Waiya Bay, surrounded by Entebbe municipal area is located in Wakiso District, Central Region, Uganda (Fig. 1). Entebbe municipality with an estimated current population of about 70 000 habitants with a population growth rate of 2.3% per annum. Waiya Bay lies between latitudes 00°04.00′N–00°06.00′N and longitudes 32°24.00′E–32°30.00′E at an estimate terrain elevation of 1134 metres above sea level. The major pollution sources are wastewater from sewage systems and agricultural runoff.

Napoleon Gulf is located is located south east of Jinja Municipality on the northern shoreline of Lake Victoria between 0° 24.34′N, 33° 14.50′E and it leads to the source of the River Nile (Fig. 1). The bay covers an area of about 200 km^2. The Gulf supports approximately half a million inhabitants with an annual population growth rate of 2.4 %. There are several fish cage farms in Napoleon Gulf. Jinja Municipality is highly industrialized, with the Nalubaale and Kiira Power Stations on the Nile River, a brewery, sugar plantations and a sugarcane processing plant, a textile factory, domestic oil producing industry, several fish processing plants and a tea estate in its vicinity. However, in the recent years the gulf has been subjected to high anthropogenic pressures. The major pollution sources are wastewater from sewage systems, industrial plants and fish cage farms. In addition, catchment wetlands which previously played the vital role of tertiary purification of effluent before discharging it into the Gulf, have long been encroached on for settlement and degraded (Ssebugere, et al., 2014).

Thurston Bay, with an area of approximately 16.5 km^2, is located in the north eastern region of Napoleon Gulf, Lake Victoria (Fig.1) with an average depth of 5 m and a maximum depth of 11 m. Unlike other nearby bays, Thurston Bay has a considerable littoral wetland region dominated by the macrophytes *Cyperus papyrus* (papyrus), *Phragmites mauritianus* (reeds), *Typha domingensis* (cat- tails), *Vossia cuspidata* (hippo grass) and *Eichhornia cras- sipes* (water hyacinth). Thurston Bay serves as drainage to a series of streams from Kakira sugar plantations and Buvuma channel from the Entebbe area.

Table S1: Location of sampling sites

sites (**Murchison Bay**)	Location	Sites (**Waiya bay**)	Location	Sites (**Napoleon gulf**)	Location
Site 1 (Nakivubo)					
NK1	N00° 17.493´; E032° 38.184´	W1	N00° 05.393´; E032° 27.357´	N1	N00° 27.051´; E033° 15.287´
NK2	N00° 17.508´; E032° 38.165´	W2	N00° 05.354´; E032° 27.332´	N2	N00° 27.104´; E033° 15.225´
NK3	N00° 17.536´; E032° 38.172´	W3	N00° 05.314´; E032° 27.290´	N3	N00° 27.174´; E033° 15.064´
NK4	N00° 17.552´; E032° 38.206´	W4	N00° 05.278´; E032° 27.270´	N4	N00° 27.155´; E033° 15.002´
NK5	N00° 17.564´; E032° 38.236´	W5	N00° 05.226´; E032° 27.229´	N5	N00° 27.112´; E033° 15.008´
NK6	N00° 17.566´; E032° 38.279´	W6	N00° 05.192´; E032° 27.176´	N6	N00° 26.324´; E033° 14.902´
NK7	N00° 17.358´; E032° 38.311´	W7	N00° 05.150´; E032° 27.088´	N7	N00° 26.319´; E033° 14.855´
NK8	N00° 17.283´; E032° 38.241´	W8	N00° 05.115´; E032° 27.046´	N8	N00° 26.149´; E033° 14.564´
NK9	N00° 17.281´; E032° 38.202´	W9	N00° 05.049´; E032° 27.012´	N9	N00° 26.063´; E033° 14.387´
NK10	N00° 17.225´; E032° 38.206´	W10	N00° 04.980´; E032° 26.991´	N10	N00° 26.005´; E033° 14.301´
Site 2 (Luzira)		W11	N00° 04.964´; E032° 27.978´	N11	N00° 25.945´; E033° 14.260´
L1	N00° 17.169´; E032° 39.532´	W12	N00° 04.951´; E032° 27.946´	N12	N00° 25.911´; E033° 14.279´
L2	N00° 17.179´; E032° 39.476´	W13	N00° 04.932´; E032° 27.917´	N13	N00° 24.828´; E033° 13.163´
L3	N00° 17.206´; E032° 39.387´	W14	N00° 04.894´; E032° 27.875´	N14	N00° 24.730´; E033° 12.969´
L4	N00° 17.230´; E032° 39.340´	W15	N00° 04.869´; E032° 27.845´	N15	N00° 24.688´; E033° 12.899´
L5	N00° 17.266´; E032° 39.298´				
L6	N00° 17.304´; E032° 39.285´	Sites (**Thurston bay**)	Location		
L7	N00° 17.312´; E032° 39.254´	T1	N00° 27.948´; E033° 22.490´		
L8	N00° 17.242; E032° 39.233´	T2	N00° 27.836´; E033° 22.389´		
L9	N00° 17.234´; E032° 39.171´	T3	N00° 27.741´; E033° 22.314´		
L10	N00° 17.332´; E032° 39.144´	T4	N00° 27.665´; E033° 22.243´		
L11	N00° 17.342´; E032° 39.141´	T5	N00° 27.597´; E033° 22.191´		
L12	N00° 17.345´; E032° 39.137´	T6	N00° 27.506´; E033° 22.153´		
Site 3 (Gaba)		T7	N00° 27.411´; E033° 22.119´		
G1	N00° 15.047´; E032° 38.389´	T8	N00° 27.347´; E033° 22.063´		
G2	N00° 15.061´; E032° 38.342´	T9	N00° 27.302´; E033° 22.020´		
G3	N00 15.095; E032 38.296	T10	N00° 27.298´; E033° 21.981´		
G4	N00° 16.316´; E032° 38.732´	T11	N00° 27.256´; E033° 21.939´		
G5	N00° 17.384´; E032° 39.814´	T12	N00° 27.231´; E033° 22.907´		
G6	N00° 17.501´; E032° 39.814´	T13	N00° 27.204´; E033° 22.876´		
G7	N00° 17.398´; E032° 39.817´	T14	N00° 27.180´; E033° 22.842´		
G8	N00° 17.384´; E032° 39.814´	T15	N00° 27.135´; 0E33° 22.781´		

Table S2: Characteristics of the sampling sites in the four bays of Lake Victoria

Bay name	Sampling sites	Sampling site characteristics
Murchison	NK 1, NK2, NK3, NK4, NK5, NK6, NK7, NK8, NK9, NK10	- Area at the mouth of Nakivubo Channel (the main recipient of sewage effluents, industrial waste and municipal waste from Kampala City and its suburbs, via the Nakivubo Channel) - Urban area influenced by wastewater discharges (surrounded by two WWTPs)
	L1, L2, L3, L4, L5, L6, L7, L8, L9, L10	- Area influenced significantly by both industrial (including various pharmaceutical industries) and commercial and agriculture activities - Area surrounded by two WWTPs
	G1, G2, G3, G4, G5, G6, G7, G8	- Area surrounded by three water treatment plants **NB:** Samples NK1-10 were collected closest to Nakivubo Channel, samples L1-12 were collected about 0.9 kilometres from Nakivubo channel close to Luzira (near a pharmaceutical industry) whereas samples G1-8 were collected about 4 kilometres from Nakivubo channel close to water treatment plants (Gaba).
Waiya	W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13, W14, W15	Area influenced by agriculture and shipping activities Urban area influenced by wastewater discharges (surrounded by one WWTP)
Napoleon	N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11, N12, N13, N14, N15	Area influenced significantly by urban industry and agriculture activities (including fish cages situated in the shallow ends of the Lake). Urban area influenced by wastewater discharges (surrounded by one WWTP)
Thurston	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15	Area influenced by both industry and rural agriculture activities

Table S3: ***Water quality parameters for the samples***

Sample no.	**pH**	**Temp. °C**	**TDS (mg/L)**	**Conductivity (µS/cm)**	**Turbidity (NTU)**	**Total Alkalinity (mg/L)**	**Total hardness (mg/L)**
NK1	7.48	23.1	152	286.2	9	83	72
NK2	7.24	23.0	158	291.1	8	80	70
NK3	7.27	23.1	165	307.0	10	82	74
NK4	7.24	23.1	162	296.0	8	79	71
NK5	7.37	23.1	149	278.0	8	73	66
NK6	7.38	23.0	143	263.6	9	81	69
NK7	7.65	23.1	115	214.3	10	85	76
NK8	7.51	22.9	121	230.9	8	83	70
NK9	7.46	23.0	130	243.0	8	78	54
NK10	7.29	23.1	126	221.1	6	76	59
L1	7.69	22.8	70.4	131.0	5	64	44
L2	7.55	22.8	71.3	131.2	4	67	41
L3	7.27	22.7	70.8	131.4	4	66	34
L4	7.52	22.8	70.9	130.8	2	61	50
L5	7.35	22.7	70.6	130.5	4	65	47
L6	7.27	22.7	73.2	136.4	6	62	42
L7	7.44	22.8	72.1	134.2	8	64	36
L8	7.53	22.8	72.5	135.7	7	67	40
L9	7.67	22.8	71.2	132.6	6	69	34
L10	7.65	22.7	72.8	131.5	6	66	38
L11	7.61	22.7	71.7	132.0	6	65	38
L12	7.64	22.9	71.3	132.6	6	69	41
G1	7.52	23.0	64.7	120.4	0	65	30
G2	7.54	22.8	65.1	121.0	2	61	34
G3	7.45	22.8	66.6	123.9	2	56	42
G4	7.51	22.8	65.8	124.9	1	59	39
G5	7.02	22.9	86.8	161.3	4	56	28
G6	7.05	22.7	84.9	160.7	4	58	30
G7	7.06	22.8	84.0	156.4	6	60	22
G8	7.00	22.8	83.5	158.0	5	59	26
W1	7.19	23.0	55.0	101.8	8	52	28
W2	7.31	23.1	55.6	101.0	6	50	32
W3	7.42	23.1	54.0	101.3	4	55	32
W4	7.42	22.9	54.8	101.3	6	53	26
W5	7.44	23.2	54.0	100.8	4	47	28
W6	7.52	23.1	54.1	101.0	4	51	31
W7	7.45	23.1	53.9	101.3	6	50	27
W8	7.40	22.9	54.0	100.5	4	50	28
W9	7.44	22.8	53.5	101.4	5	54	25
W10	7.49	22.8	53.2	101.4	5	51	29
W11	7.41	22.9	53.0	101.7	3	55	32
W12	7.51	22.8	53.1	101.0	4	53	31
W13	7.42	22.8	53.2	100.5	4	56	35
W14	7.51	22.8	53.0	101.1	5	55	31
W15	7.47	22.8	53.2	101.1	4	57	33
N1	8.34	22.5	57.1	107.6	1	61	30
N2	8.07	22.6	57.7	106.9	0	57	26
N3	8.20	22.6	57.2	108.1	1	60	44
N4	8.12	22.6	57.2	107.4	1	64	32
N5	8.35	22.5	56.8	105.3	0	61	37
N6	7.50	22.6	56.0	105.1	0	65	29
N7	8.18	22.6	56.5	105.8	0	59	30
N8	7.87	22.6	56.1	105.3	1	63	36

N9	7.40	22.6	56.6	105.3	1	60	41
N10	7.70	22.6	55.8	105.0	1	64	39
N11	7.80	22.5	55.8	105.4	1	57	36
N12	8.30	22.5	55.3	105.4	0	65	38
N13	8.23	22.5	55.0	106.1	1	65	43
N14	8.04	22.6	55.2	105.6	1	62	39
N15	8.12	22.6	55.1	105.1	1	64	41
T1	7.58	22.5	59.3	111.0	2	55	32
T2	7.78	22.5	60.7	111.6	2	52	35
T3	8.30	22.5	59.1	111.3	2	57	33
T4	7.80	22.5	59.0	113.0	3	61	37
T5	7.64	22.5	60.1	112.6	1	59	42
T6	7.66	22.5	58.9	110.3	0	66	46
T7	7.75	22.5	62.3	114.0	3	63	45
T8	7.71	22.5	79.0	150.6	2	58	41
T9	7.98	22.5	80.5	151.2	5	61	39
T10	7.82	22.5	83.0	155.7	6	60	36
T11	7.78	22.5	81.5	117.3	5	63	40
T12	7.71	22.5	80.7	150.1	4	60	40
T13	7.68	22.5	82.8	150.4	4	65	42
T14	7.75	22.5	82.0	149.2	3	61	36
T15	7.89	22.5	83.1	150.0	4	59	39

Table S4: Toxicological data for the target compounds

Compound	Trophic level (organism)	Species	Toxicological end point	Toxicological data (mg/L)	Reference
Trimethoprim	Algae	Anabaena variabilis	Growth inhibition (144)	3.1 (NOEC)	Ando et al., 2007
	Crustacean	Daphnia magna	Reproduction (21d)	6 (NOEC)	Santos et al., 2010
	Algae	S. capricornutum	Growth inhibition (72h)	25.5 (NOEC)	Santos et al., 2010
	Fish	B.rerio	Reproduction (72h)	100 (NOEC)	Halling- Sørensen et al., 2000
Sulfamethoxazole	Algae	Synechococcus leopolensis	Growth inhibition (96h)	0.0059 (NOEC)	Ferrari et al., 2003
	Algae	Pseudokirchneriella Subcapitata	Growth inhibition (96h)	0.09 (NOEC)	Ferrari et al., 2003
	Crustacean	Ceriodaphnia dubia	Reproduction (7d)	0.25 (NOEC)	Ferrari et al., 2003
	Fish	Danio rerio	Mortality (10d)	>8 (NOEC)	Ferrari et al., 2003
Sulfamethazine	Crustacean	D. magna	Reproduction (21d)	1.563 (NOEC)	Santos et al., 2010
Sulfacetamide	Mouse		Mortality	16500 (LC$_{50}$)	Silva et al., 2015
Oxytetracycline	Algae	P. subcapitata	Growth inhibition (144h)	0.183 (NOEC)	Ando et al., 2007
	Algae	Anabaena cylindrica	Growth inhibition (144h)	0.0031 (NOEC)	Ando et al., 2007
	Algae	M. aeruginosa	Growth inhibition (144h)	0.031 (NOEC)	Ando et al., 2007
	Algae	S. capricornutum	Growth inhibition (72h)	0.183 (NOEC)	Santos et al., 2010
	Cnidarian	Hydra attenuata	Morphology (96h)	50 (NOEC)	Santos et al., 2010
Tetracycline	Crustacean	D. magna	Reproduction (21d) Growth rate (21d)	5 (NOEC) 2 (NOEC)	Kim et al., 2012
Erythromycin	Algae	P. subcapitata	Growth inhibition (72h)	0.020 (EC50)	Santos et al., 2010
	Algae	M. aeruginosa	Growth inhibition (144h)	0.023 (EC50)	Ando et al., 2007
	Algae	Anabaena cylindrica	Growth inhibition (144h)	0.035 (EC50)	Ando et al., 2007
	Algae	P. subcapitata	Growth inhibition (144h)	0.0366 (EC50)	Ando et al., 2007
	Algae	S. leopoldensis	Growth inhibition (144h)	0.16 (EC50)	Ando et al., 2007
	Crustacean	C. dubia	Growth inhibition (7d)	0.22 (EC50)	Santos et al., 2010
Azithromycin	Crustacean	D. magna	Growth inhibition	120 (EC50)	Brausch et al., 2012
Ciprofloxacin	Amphibian	Rhinella arenarum	Growth rate (96h)	0.001 (NOEC)	Peltzer et al., 2017
	Algae	P. subcapitata	Growth inhibition (96h)	1.09 (NOEC)	Martins et al., 2012
	Crustacean	D. magna	Size of neonates (48h) Fecundity (48h) Growth rate (48h)	1.8 (NOEC) 5.19 (NOEC) 8.82 (NOEC)	Martins et al., 2012
	Crustacean	D. magna	Reproduction (48h)	60 (NOEC)	Halling- Sørensen et al., 2000
	Fish	B.rerio	Reproduction (72h)	100 (NOEC)	Halling- Sørensen et al., 2000
Levofloxacin	Crustacean	D. magna	Reproduction (21d)	0.063 (NOEC)	Santos et al., 2010
	Algae	P. subcapitata	Growth inhibition (96h)	0.31(NOEC)	Santos et al., 2010
Norfloxacin	Algae	M. aeruginosa	Growth inhibition (144h)	0.062 (EC50)	Ando et al., 2007
	Algae	Anabaena cylindrica	Growth inhibition (144h)	0.053 (EC50)	Ando et al., 2007
	Algae	S. leopoldensis	Growth inhibition (144h)	0.63 (EC50)	Ando et al., 2007
	Algae	C. vulgaris	Growth inhibition	10.4 (EC50)	Santos et al., 2010
	Rotifer	B. calyciflorus	Mortality (24h)	29.88 (LC50)	Santos et al., 2010
Enoxacin	Mouse		mortality	248.9 (LC$_{50}$)	Weng et al., 2017
Ibuprofen	Cnidarian	Hydra attenuate	Morphology (96h)	0.1 (NOEC)	Quinn et al., 2008
	Mollusc	P. carinatus	Growth inhibition (21d) Reproduction (21d) Survival	1.02 (NOEC) 2.43 (NOEC) 5.36 (NOEC)	Santos et al., 2010
	Crustacean	D. magna	survival	20 (NOEC)	Santos et al., 2010
Diclofenac	Fish	F. fario	Histopathological alterations (21d)	0.0005 (NOEC)	Santos et al., 20104
	Crustacean	Ceriodaphnia dubia	Reproduction (7d)	1 (NOEC)	Ferrari et al., 2003

	Fish	Danio rerio	Mortality (10d)	4 (NOEC)	Ferrari et al., 2003
	Algae	P. subcapitata	Growth inhibition (96h)	10 (NOEC)	Ferrari et al., 2003
Acetaminophen	Crustacean	D. magna	Mortality (48h)	6 (LC50)	US EPA, 1992
	Algae	S, subspicatus	Growth inhibition (72h)	134 (EC50)	Santos et al., 20104
	Fish	O.latipes	Mortality (96h)	>160 (LC50)	Santos et al., 20104
Carbamazepine	Crustacean	C. dubia	Reproduction (7d)	0.025 (NOEC)	Ferrari et al., 2003
	Rotifer	B. calyciflorus	Reproduction (48h)	0.377 (NOEC)	Ferrari et al., 2003
	Algae	S. leopoldensis	Growth inhibition (96h)	17.5 (NOEC)	Ferrari et al., 2003
	Fish	Danio rerio	Mortality (10d)	25 (NOEC)	Ferrari et al., 2003
Atenolol	Fish	P. promelas	Growth inhibition (28d)	1.0 (NOEC)	Brausch et al., 2012
	Fish	P. promelas	Condition index (21d) Growth inhibition (28d)	1.0 (NOEC) 3.2 (NOEC)	Santos et al., 2010
	Crustacean	D. magna	Reproduction (21d)	1.48 (NOEC)	Brausch et al., 2012
Metoprolol	Crustacean	D. magna	Body mass (9d)	6.15 (NOEC)	Santos et al., 2010

Table S5: No observed effect concentrations (NOECs) and assessment factors (AF) for calculating predicted no effect concentrations (PNECs)

Compound	**NOEC (mg/L) (unless stated otherwise)**	**No. of Trophic levels**	**Assessment factor (AF)**	**PNEC (mg/L)**
Trimethoprim	3.1[m],6[b], 25.5[b], 100[b]	3	10	0.31
Sulfamethoxazole	0.0059[d], 0.09[d], 0.25[d]	3	10	0.00059
Sulfamethazine	1.563[b]	1	100	0.01563
Sulfacetamide	16500[g] (LC_{50})		1000	16.5
Oxytetracycline	0.0031[m], 0.031[m], 0.183[b,m], 50[b]	2	50	0.000062
Tetracycline	2[l], 5[l]	1	100	0.02
Erythromycin	0.020[b], 0.023[m], 0.035[m], 0.0366[m,b], 0.16[m], 0.22[b] (EC_{50})		1000	0.00002
Azithromycin	120[h] (EC_{50})		1000	0.12
Ciprofloxacin	0.001[n], 1.09[k], 1.8[k], 5.19[k], 8.82[k], 60[f], 100[f]	2	10	0.0001
Levofloxacin	0.063[b], 0.31[b],	2	50	0.00126
Norfloxacin	0.062[m], 0.053[m], 0.63[m], 10.4[b], 29.88[b] (EC_{50})		1000	0.000062
Enoxacin	248.9[i] (LC_{50})		1000	0.2489
Ibuprofen	0.1[j], 1.02[b], 2.43[b], 5.36[b], 20[b]	1	50	0.002
Diclofenac	0.0005[b],1[d], 4[d],10[d]	3	10	0.00005
Acetaminophen	6[a], 134[b] (LC_{50})		1000	0.006
Carbamazepine	0.025[d], 0.377[d],17.5[d], 25[d]	3	10	0.0025
Atenolol	1.0[b, i], 1.48[i], 3.2[b]	2	50	0.02
Metoprolol	6.15[b]	1	100	0.0615

PNEC= lowest NOEC/AF [European Commission's Technical Guidance Document on risk assessment (European Commission, 2003)]

[a] US EPA, 1992 (acute data)
[b] Santos et al 2010
[c] Schwaiger et al., 2004
[d] Ferrari et al., 2004
[f] Halling- Sørensen et al., 2000 (acute data)
[g] Silva etal., 2015 (acute data)
[h] Brausch et al., 2012

[i] Weng et al., 2017 (acute data)
[j] Quinn et al., 2008
[k] Martins et al., 2012
[l] Kim et al., 2012
[m] Ando et al., 2007
[n] Peltzer et al., 2017

Table S6: Optimized LC/MS/MS parameters for target analytes and internal standards

Analytes					Internal Standards				
Compound	Precursor ion	Product ion(s)	Fragmentor (V)	CE (eV)	Compound	Precursor ion	Product ion(s)	Fragmentor (V)	CE (eV)
Trimethoprim	291.2	230.1 123.1	128 128	20 24	**Trimethoprim-d$_3$**	294.2	230.1 123.1	166 166	24 24
Sulfamethoxazole	254.1	156 92.1	103 103	12 24	**Sulfamethoxazole-d$_4$**	258.1	160.1 96.1	117 117	12 28
Sulfamethazine	297.1	186 124.1	124 124	13 21	**Thiabendazole-d$_4$**	206.1	179.1 178.1	138 138	28 28
Sulfacetamide	215	156.1 92.1	74 74	8 20	**Erythromycin-^{13}C-d$_3$**	720.6	162.2 562.5	162 162	25 20
Metronidazole	172.1	128.1 82.1	84 84	12 28	**Ciprofloxacin-d$_8$**	340.2	322.2 249.2	133 133	20 24
Oxytetracycline	461.2	426.1 201.1	119 119	17 41	**Ibuprofen-d$_3$**	210.2	164.2	59	8
Tetracycline	445.2	410.1 427	110 110	15 5	**Diclofenac-d$_4$**	300	219.2 218.2	103 103	16 32
Erythromycin	734.5	158.2 83.1	157 157	32 72	**Carbamazepine-d$_{10}$**	247.2	204.2 202.2	132 132	20 36
Azithromycin	749.5	158.2 591.4	221 221	40 32	**Fluoxetine-d$_5$**	315.2	153.2	69	0
Roxithromycin	837.5	158.1 116.1	197 197	40 48	**Atenolol-d$_7$**	274.2	145.1 57.1	113 113	28 36
Ciprofloxacin	332.2	314.1 245.1	133 133	20 24					
Levofloxacin	362.2	318.2 261.1	113 113	16 28					
Norfloxacin	320.1	302.1 233.1	143 143	20 24					
Sparfloxacin	393.2	292.1 251.1	167 167	24 32					
Enoxacin	321.1	303.2 232.1	128 128	20 36					
Ibuprofen	207.1	161.2	84	8					
Acetaminophen	152.1	110.1 93.1	113 113	16 24					
Diclofenac	296	214 250	78 78	36 8					
Carbamazepine	237.1	194.2 179.2	140 140	20 20					
Diazepam	285.1	154.1 193.1	133 133	328 32					
Fluoxetine	310.1	148.1	108	4					
Bezafibrate	362.1	139 121.1	133 133	20 28					
Atenolol	267.2	145.1 56.1	143 143	24 32					
Metoprolol	268.2	56.1 77.1	98 98	32 60					

CE- Collision Energy

Table S7: Recoveries, RSD, LOD, LOQ and linearity of the target pharmaceuticals

	Blank spike recovery range (ng/L)		**Blank spike recoveries Mean (%) ± RSD (%)**		**Sample spike recovery range (ng/L)**		**Sample spike recoveries Mean (%) ± RSD (%)**		**LOD (ng/L)**	**LOQ (ng/L)**	**Linearity (r^2) [a]**
Analyte	**50 ng/L**	**100 ng/L**	**50 ng/L**	**100 ng/L**	**50 ng/L**	**100 ng/L**	**50 ng/L**	**100 ng/L**			
Trimethoprim	84-103	82-87	95 ± 5.2	84 ± 2.4	86-93	81-84	89 ± 2.5	82 ± 1.6	1.7	5.9	0.9999
Sulfamethoxazole	89-115	95-98	105 ± 7.0	97 ± 1.2	95-106	90-95	100 ± 4.2	92 ± 3.0	0.3	1.9	0.9999
Sulfamethazine	108-119	98-111	115 ± 2.4	106± 6.9	117-128	107-113	121 ± 2.8	111 ± 3.2	0.3	1.2	0.9995
Sulfacetamide	68-70	63-65	69 ± 0.7	64 ± 1.0	62-63	50-53	63 ± 0.4	52 ± 2.1	0.2	0.9	0.9999
Oxytetracycline	96-110	100-105	101 ± 3.7	103 ± 2.4	110-119	111-114	114 ± 3.1	113 ± 1.5	3.4	13	0.9996
Tetracycline	66-72	76-77	69 ± 2.0	76 ± 0.6	93-107	97-110	101 ± 3.5	105 ± 6.9	0.2	0.9	0.9996
Erythromycin	86-98	76-93	91 ± 3.2	87 ± 9.5	92-97	95-97	96 ± 1.4	96 ± 1.6	0.2	0.8	0.9944
Azithromycin	76-84	51-84	79 ± 2.7	69 ± 13	108-122	91-104	116 ± 5.2	99 ± 6.8	4.1	14	0.9981
Ciprofloxacin	68-74	75-77	70 ± 1.9	76 ± 1.0	84-86	72-74	85 ± 1.0	73 ± 0.1	3.7	11	0.9946
Levofloxacin	70-76	67-73	73 ± 1.5	70 ± 2.9	83-99	80-91	91 ± 3.9	84 ± 5.9	0.2	0.8	0.9996
Norfloxacin	58-73	68-72	65 ± 4.0	70 ± 1.8	74-78	70-84	75 ± 1.3	76 ± 7.2	1.6	6.2	0.9962
Enoxacin	68-71	60-73	70 ± 0.7	67 ± 6.3	64-70	68-70	68 ± 1.6	69 ± 0.9	2.2	15	0.9994
Ibuprofen	92-106	87-94	101 ± 4.1	90 ± 3.6	98-101	88-91	99 ± 0.6	89± 2.0	0.5	1.9	0.9991
Diclofenac	84-106	87-92	98 ± 6.0	90 ± 2.7	97-99	98-100	97 ± 0.5	98 ± 1.1	0.4	1.5	0.9999
Acetaminophen	65-73	60-72	70 ± 2.0	67 ± 6.2	60-73	65-68	65± 3.5	67 ± 1.4	0.7	2.4	0.9994
Carbamazepine	91-118	95-96	108 ± 7.5	96 ± 0.3	100-118	105-121	110 ± 4.6	113 ± 10	0.9	3.2	0.9995
Atenolol	87-121	85-115	110 ± 10	97 ± 15	82-91	97-105	87 ± 3.3	101 ± 5.4	1.6	6.9	0.9999
Metoprolol	85-102	80-95	95 ± 4.4	86 ± 8.3	80-103	96-107	92 ± 5.8	102 ± 5.3	0.5	2.0	0.9999
Roxithromycin	88-114	77-108	104 ± 6.9	91 ± 15	108-117	109-115	112± 2.4	112 ± 3.4	0.4	1.6	0.9986
Sparfloxacin	99-122	99-105	114 ± 6.8	102 ± 2.7	114-131	108-125	123± 5.1	117 ± 8.8	0.2	0.9	0.9944
Metronidazole	51-57	49-58	54 ± 1.5	53 ± 4.7	55-57	50-54	56 ± 0.6	52 ± 2.0	0.3	1.1	0.9999
Diazepam	79-99	78-84	92 ± 5.7	82 ± 2.9	79-85	67-77	83 ± 1.7	73 ± 5.5	1.2	4.5	0.9996
Fluoxetine	85-105	86-87	95 ± 4.8	87 ± 0.2	95-101	97-101	98 ± 1.4	98 ± 2.6	1.1	3.9	0.9999
Bezafibrate	86-109	84-90	101 ± 6.5	87± 3.2	95-97	92-96	96 ± 0.6	93 ± 2.3	1.2	4.3	0.9999

RSD-Relative standard deviation, LOD-Limit of detection, LOQ-Limit of quantification

[a] Calibration curves (1 μg/L to 1000 μg/L for each compound)

Table S8: Comparison of surface water pharmaceutical concentrations (ng/L) in present study with those from previous studies

Compound	**Area / location**	**Concentration (ng/L)**	**Reference (s)**
Trimethoprim	U.S streams, United States	n.d-710	Kolpin et al. (2002)
	Major river, United States	2.2-10.9	Padhye et at. (2014)
	Mississippi River, United States	4.6	Wang et al. (2011)
	Tennessee River basin, United States	2.3-63.3	Conley et al. (2008)
	Ebro River basin, Spain	n.d-29.9	Silva et al. (2011)
Sulfamethoxazole	U.S streams, United States	n.d-1900	Kolpin et al. (2002)
	Major river, United States	n.d-7.4	Padhye et at. (2014)
	Mississippi River, United States	13.7	Wang et al. (2011)
	Tennessee River basin, United States	3.1-33	Conley et al. (2008)
	River Kisat, Kenya	n.d	Kimosop et al. (2016)
	River Sosiani, Kenya	n.d	Kimosop et al. (2016)
Sulfamethazine	U.S streams, United States	n.d-220	Kolpin et al. (2002)
	Ebro River basin, Spain	n.d	Silva et al. (2011)
Oxytetracycline	U.S streams, United States	n.d-34	Kolpin et al. (2002)
Tetracycline	U.S streams, United States	n.d-110	Kolpin et al. (2002)
Erythromycin	Ebro River basin, Spain	n.d-42.2	Silva et al. (2011)
Ciprofloxacin	U.S streams, United States	n.d-30	Kolpin et al. (2002)
	Tennessee River basin, United States	4.7-54.2	Conley et al. (2008)
	River Kisat, Kenya	130-170	Kimosop et al. (2016)
	River Sosiani, Kenya	90-240	Kimosop et al. (2016)
Levofloxacin	Major river, United States	n.d-1.3	Padhye et at. (2014)
	Tennessee River basin, United States	6.2-59.2	Conley et al. (2008)
Norfloxacin	U.S streams, United States	n.d-120	Kolpin et al. (2002)
Ibuprofen	U.S streams, United States	n.d-1000	Kolpin et al. (2002)
	Major river, United States	n.d-133	Padhye et at. (2014)
	Mississippi River, United States	16.6	Wang et al. (2011)
	Pearl River system, China	n.d-113	Zhao et al. (2009)
	Ria River, Acoruna, Spain	n.d	Rodil et al. (2009)
	Ebro River basin, Spain	n.d-541	Silva et al. (2011)
	River Kabul, Pakistan	11.8	Khan et al. (2018)
Diclofenac	Major river, United States	n.d-24	Padhye et at. (2014)
	Pearl River system, China	8.3-114	Zhao et al. (2009)
	Ria River, Acoruna, Spain	n.d	Rodil et al. (2009)
	Ebro River basin, Spain	n.d-148	Silva et al. (2011)
	River Kabul, Pakistan	0.18	Khan et al. (2018)
Acetaminophen	U.S streams, United States	n.d-10000	Kolpin et al. (2002)
	Major river, United States	n.d-19	Padhye et at. (2014)
	Mississippi River, United States	5.3	Wang et al. (2011)
	Tennessee River basin, United States	2.1-12.3	Conley et al. (2008)
	Ebro River basin, Spain	n.d-872	Silva et al. (2011)
	River Kabul, Pakistan	3650	Khan et al. (2018)
Carbamazepine	Major river, United States	0.5-4.1	Padhye et at. (2014)
	Mississippi River, United States	8.4	Wang et al. (2011)
	Tennessee River basin, United States	2.9-23.1	Conley et al. (2008)
	Pearl River system, China	10.8-40.6	Zhao et al. (2009)
	Ria River, Acoruna, Spain	n.d	Rodil et al. (2009)
	Ebro River basin, Spain	n.d-53.8	Silva et al. (2011)
Atenolol	Major river, United States	n.d	Padhye et at. (2014
	Ria River, Acoruna, Spain	n.d	Rodil et al. (2009)
	Ebro River basin, Spain	n.d-1237	Silva et al. (2011)
Metoprolol	Major river, United States	0.1-0.3	Padhye et at. (2014)
	Ebro River basin, Spain	n.d-33.9	Silva et al. (2011)

n.d-not detected

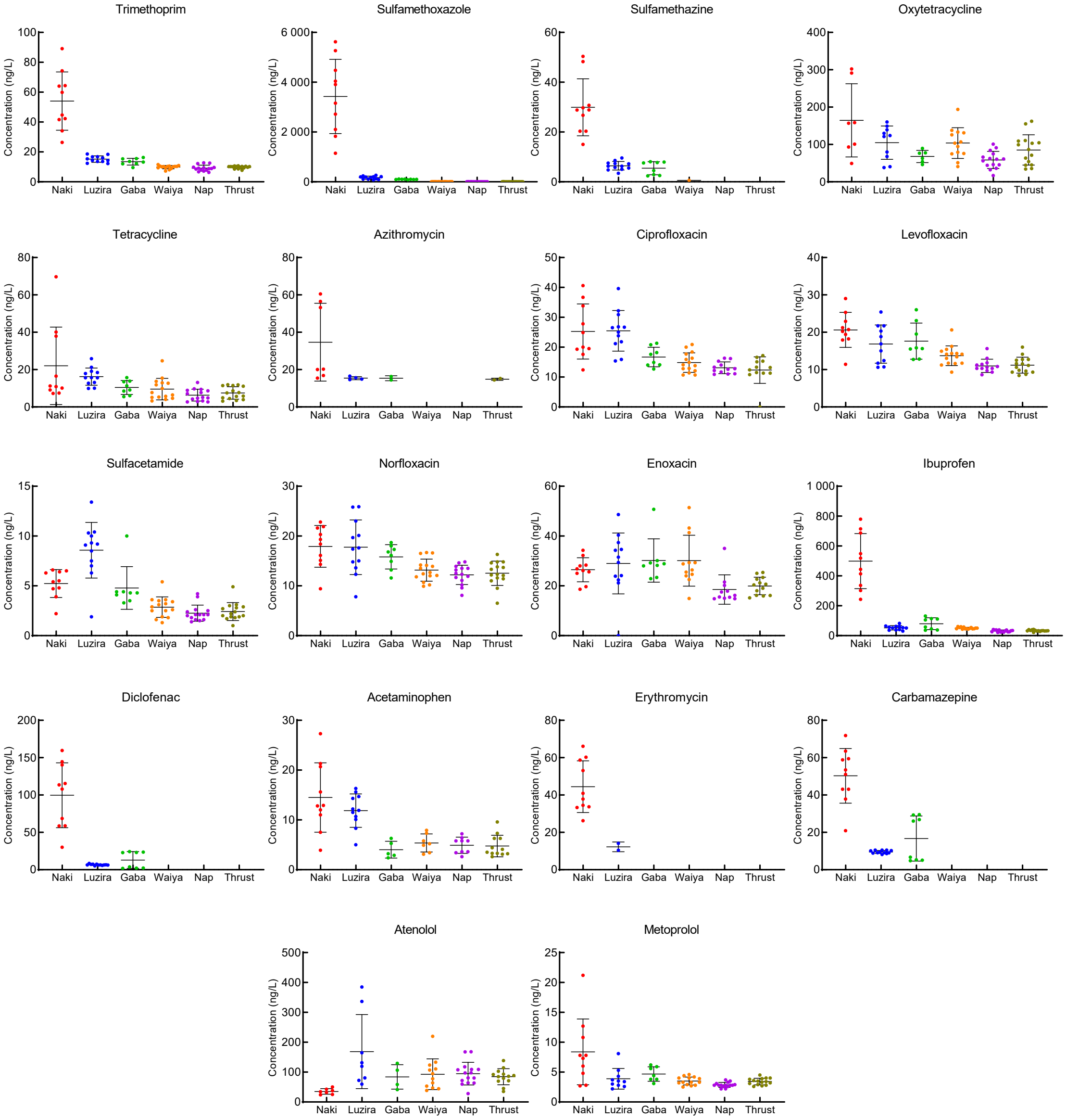

Fig. S1. Means and standard deviations of the compounds tested, for the six sampling regions.

Table S9: Concentrations (ng/L) and ranges of selected pharmaceuticals in water from four Bays of Lake Victoria

	Murchison bay (N=30)					**Waiya bay(N=15)**					**Napoleon gulf (N=15)**					**Thurston bay (N=15)**				
Analyte	%det	Min	Max	Median	Mean ± SD	%det	Min	Max	Median	Mean ± SD	%det	Min	Max	Median	Mean ± SD	%det	Min	Max	Median	Mean ± SD
Trimethoprim	100	9.5	89	16	28 ± 21	100	7.2	12	10	9.8 ± 1.1	100	6.3	13	8.9	9.2 ± 2.0	100	7.7	11	10	9.7 ± 0.9
Sulfamethoxazole	100	78	5600	190	1200 ± 1700	100	4	9	5.1	5.5 ± 1.5	100	2.9	5.8	4.3	4.2 ± 0.8	100	2.4	5.1	3.2	3.3 ± 0.7
Sulfamethazine	100	2.4	50	7.6	14 ± 13	0	ND	ND	ND	ND	0	ND	ND	ND	ND	0	ND	ND	ND	ND
Sulfacetamide	100	1.9	13	6.3	6.5 ± 2.8	100	1.3	5.4	2.9	2.9 ± 1	100	1.4	4.2	2.1	2.3 ± 0.8	100	1	4.9	2.2	2.4 ± 0.9
Oxytetracycline	91	38	300	93	113 ± 70	87	41	190	100	100 ± 40	100	17	100	60	59 ± 23	100	34	160	86	85 ± 40
Tetracycline	100	5.5	70	13	17 ± 12	100	3.2	25	7.7	9.5 ± 5.8	100	2.7	13	5.1	6.3 ± 3.2	100	3.1	12	7.5	7.5 ± 3.3
Erythromycin	40	10	66	36	39 ± 18	0	ND	ND	ND	ND	0	ND	ND	ND	ND	0	ND	ND	ND	ND
Azithromycin	43	14	61	17	26 ± 18	0	ND	ND	ND	ND	0	ND	ND	ND	ND	13	14	15	15	15 ± 0.6
Ciprofloxacin	100	12	41	21	23 ± 7.9	100	11	21	14	15 ± 3.3	80	11	16	13	13 ± 2	73	11	17	13	14 ± 2.3
Levofloxacin	97	11	29	19	18 ± 5.0	100	9.3	21	14	14 ± 2.6	87	8.6	16	11	11 ± 1.8	100	8.4	16	11	11 ± 2.1
Norfloxacin	100	7.8	26	17	17 ± 4.4	100	9.9	17	13	13 ± 2.2	93	8.1	15	12	12 ± 1.9	100	6.5	16	12	13 ± 2.4
Enoxacin	97	19	51	28	29 ± 7.6	87	15	51	29	31 ± 10	73	15	35	16	19 ± 5.9	87	15	25	20	20 ± 3.5
Ibuprofen	100	31	780	73	200 ± 230	100	43	61	49	50 ± 5.9	100	21	41	32	31 ± 6.8	100	21	42	33	33 ± 5
Diclofenac	100	1.8	160	7.9	39 ± 50	0	ND	ND	ND	ND	0	ND	ND	ND	ND	0	ND	ND	ND	ND
Acetaminophen	87	2.4	27	12	11 ± 6.1	47	3.1	7.9	5.2	5.4 ± 1.8	60	2.6	7.2	5.8	4.9 ± 1.6	80	2.6	9.6	3.8	4.7 ± 2.2
Carbamazepine	100	4.8	72	11	25 ± 21	0	ND	ND	ND	ND	0	ND	ND	ND	ND	0	ND	ND	ND	ND
Atenolol	63	24	380	60	100 ± 100	80	39	220	86	93 ± 51	100	28	160	97	95 ± 38	87	35	130	86	85 ± 27
Metoprolol	93	2.2	21	4.4	5.8 ± 4.0	93	2.5	4.6	3.3	3.5 ± 0.7	100	2.2	3.7	2.8	2.9 ± 0.4	100	2.6	4.5	3.4	3.4 ± 0.6

%det - percent of samples in which the analyte was detected; SD - Standard deviation; ND-Not detected

Table S10: Mean concentrations (ng/L) and ranges of pharmaceuticals in water from the three regions of Murchison bay

Sampling site	**Nakivubo region (n=10)**					**Luzira (n = 12)**					**Gaba (n = 8)**				
Analyte	%det	Min	Max	Median	Mean±SD	%det	Min	Max	Median	Mean±SD	%det	Min	Max	Median	Mean±SD
Trimethoprim	100	26	89	52	54 ± 19	100	12	19	15	15 ± 2.1	100	9.5	16	13	14 ± 2.2
Sulfamethoxazole	100	1100	5600	3500	3400 ±1400	100	78	260	180	160 ± 61	100	82	110	99	99 ± 10
Sulfamethazine	100	15	50	29	30 ± 11	100	3.4	9.6	6.3	6.4 ± 1.7	100	2.4	8.1	6.1	5.4 ± 2.6
Sulfacetamide	100	2.2	6.6	5.5	5.2 ± 1.4	100	1.9	13	9.2	8.6 ± 2.8	100	3.3	10	4.3	4.8 ± 2.2
Oxytetracycline	70	49	300	150	160 ± 98	83	38	160	120	100 ± 44	75	46	90	70	68 ± 16
Tetracycline	100	7.2	70	11	22 ± 21	100	10	26	16	16 ± 4.6	100	5.5	16	10	10 ± 3.8
Erythromycin	100	26	66	39	45 ± 14	17	10	14	12	12 ± 2.6	0	ND	ND	ND	ND
Azithromycin	70	15	61	20	35 ± 20	33	15	17	15	15 ± 0.8	25	14	16	15	15 ± 1.4
Ciprofloxacin	100	12	41	23	25 ± 9.2	100	15	40	26	26 ± 6.8	100	13	21	16	17 ± 3.3
Levofloxacin	100	11	29	21	21 ± 4.7	92	11	25	17	17 ± 5.1	100	13	26	16	18 ± 4.8
Norfloxacin	100	9.4	23	19	18 ± 4.2	100	7.8	26	18	18 ± 5.5	100	12	19	17	16 ± 2.5
Enoxacin	100	19	34	26	27 ± 4.8	92	21	49	32	32 ± 8.5	100	23	51	29	30 ± 8.7
Ibuprofen	100	240	780	480	490 ± 180	100	31	82	53	52 ± 14	100	36	132	82	80 ± 39
Diclofenac	100	30	160	110	100 ± 43	100	5.1	8.4	6.4	6.6 ± 0.9	100	1.8	24	13	13 ± 11
Acetaminophen	100	3.9	27	13	15 ± 7.0	92	5.0	16	12	12 ± 3.3	71	2.4	6.3	3.2	4.0 ± 1.7
Carbamazepine	100	21	72	52	50 ± 15	100	8.2	11	9.3	20 ± 0.8	100	4.8	30	16	17 ± 12
Atenolol	70	24	50	34	35 ± 9.4	67	60	380	120	160 ± 124	50	42	130	83	84 ± 41
Metoprolol	100	2.7	21	7.5	8.4 ± 5.5	83	2.2	8.1	3.4	3.9 ± 2.7	88	3.1	6.2	4.4	4.7 ± 1.2

%det - percent of samples in which the analyte was detected; SD - Standard deviation; ND-Not detect

Table S11. Results of the Kruskal-Wallis analyses of the concentrations of the different compounds between the six sampling regions.

	Trimethoprim	Sulfamethoxazole	Sulfamethazine	Sulfacetamide	Oxytetracycline	Tetracycline	Erythromycin	Azithromycin	Ciprofloxacin	Levofloxacin	Norfloxacin	Enoxacin	Ibuprofen	Diclofenac	Acetaminophen	Carbamazepine	Atenolol	Metoprolol
Kruskal-Wallis p	**<0.0001**	**<0.0001**	**0.0001**	**<0.0001**	**0.0044**	**<0.0001**	< Data	**0.0087**	**<0.0001**	**<0.0001**	**0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0001**	**0.0022**	**0.0002**
Naki vs. Luzira	>0.9999	>0.9999	**0.0013**	>0.9999	>0.9999	>0.9999		0.2259	>0.9999	>0.9999	>0.9999	>0.9999	0.0757	**0.0002**	>0.9999	**0.0003**	**0.0006**	0.3748
Naki vs. Gaba	0.5877	>0.9999	**0.0014**	>0.9999	0.3662	>0.9999		0.3414	>0.9999	>0.9999	>0.9999	>0.9999	0.7105	**0.001**	**0.0054**	**0.0022**	0.5359	>0.9999
Naki vs. Waiya	**<0.0001**	**0.0006**	**0.0449**	0.1081	>0.9999	>0.9999			**0.0387**	0.1886	0.0633	>0.9999	0.0969		0.0689		**0.034**	0.2722
Naki vs. Nap	**<0.0001**	**<0.0001**		**0.002**	**0.0089**	**0.0133**			**0.002**	<0.0001	**0.0064**	**0.0608**	**<0.0001**		**0.0169**		**0.0072**	**0.0002**
Naki vs. Thurst	**<0.0001**	**<0.0001**		**0.0086**	0.6681	0.1533		0.1211	**0.0021**	**0.0001**	**0.0174**	0.2724	**<0.0001**		**0.0018**		**0.0416**	0.1594
Luzira vs. Gaba	>0.9999	>0.9999	>0.9999	>0.9999	>0.9999	>0.9999		>0.9999	0.576	>0.9999	>0.9999	>0.9999	>0.9999	>0.9999	**0.0098**	>0.9999	>0.9999	>0.9999
Luzira vs. Waiya	**0.0065**	0.0648	>0.9999	**0.0009**	>0.9999	**0.0368**			**0.0043**	>0.9999	0.119	>0.9999	>0.9999		0.1219		>0.9999	>0.9999
Luzira vs. Nap	**<0.0001**	**0.0006**		**<0.0001**	0.1193	**<0.0001**			**0.0001**	**0.0202**	**0.012**	**0.0067**	**0.0112**		**0.0323**		>0.9999	0.7888
Luzira vs. Thurst	**0.0032**	**<0.0001**		**<0.0001**	>0.9999	**0.0018**		>0.9999	**0.0001**	**0.0292**	0.0329	**0.0399**	**0.0363**		**0.0037**		>0.9999	>0.9999
Gaba vs. Waiya	0.3115	0.9701	>0.9999	0.4868	>0.9999	>0.9999			>0.9999	>0.9999	0.8118	>0.9999	>0.9999		>0.9999		>0.9999	>0.9999
Gaba vs. Nap	**0.0199**	**0.0448**		**0.0208**	>0.9999	0.4122			0.8662	**0.0063**	0.1576	**0.0112**	**0.0052**		>0.9999		>0.9999	**0.008**
Gaba vs. Thrurst	0.201	**0.0004**		0.0667	>0.9999	>0.9999		>0.9999	0.8843	**0.009**	0.3329	0.0553	**0.0157**		>0.9999		>0.9999	>0.9999
Waiya vs. Nap	>0.9999	>0.9999		>0.9999	0.0579	>0.9999			>0.9999	0.2995	>0.9999	**0.0079**	**0.002**		>0.9999		>0.9999	0.4228
Waiya vs. Thurst	>0.9999	0.076		>0.9999	>0.9999	>0.9999			>0.9999	0.4323	>0.9999	**0.0459**	**0.0081**		>0.9999		>0.9999	>0.9999
Nap vs. Thurst	>0.9999	>0.9999		>0.9999	>0.9999	>0.9999			>0.9999	>0.9999	>0.9999	>0.9999	>0.9999		>0.9999		>0.9999	0.5963

Table S12. Results of linear regression analyses between water quality criteria and compound concentrations.

Variable	Compound	Trimethoprim	Sulfamethoxazole	Sulfamethazine	Sulfacetamide	Oxytetracyclin	Tetracycline	Erythromycin	Azithromycin	Ciprofloxacin	Levofloxacin	Norfloxacin	Enoxacin	Ibuprofen	Diclofenac	Acetaminophen	Carbamazepine	Atenolol	Metoprolol	Criteria	Counts
	Data points	75	75	30	75	75	75	13	72	74	75	75	74	75	30	75	30	75	75		
pH	Slope	-17.1	-1165	-11.77	-2.7	-64.94	-9.088	-18.85	-18.94	-7.76	-6.395	-3.699	-8.044	-186.8	-61.5	-7.15	-35.26	-13.92	-2.744	No. Positive	0
	R square	0.1113	0.08637	0.03196	0.1018	0.1442	0.08909	0.02742	0.05666	0.1079	0.149	0.08832	0.07754	0.1255	0.06077	0.1569	0.1137	0.004715	0.1044	No. R^2> 0.4	0
	Sy.x	15.59	1222	13.23	2.588	50.24	9.375	18.34	17.07	7.098	4.744	3.812	8.469	159.1	49.39	5.109	20.11	64.95	2.652		
	P value	**0.0034**	**0.0105**	0.3446	**0.0053**	**0.0017**	**0.0093**	0.607	0.3929	**0.0059**	**0.0007**	**0.0101**	**0.0247**	**0.0018**	0.1891	**0.0028**	0.0684	0.6053	**0.006**	No. P < 0.05	12
Temperature	Slope	7.51	588.4	11.04	1.43	29.07	4.885	37.66	18.86	3.997	2.474	2.022	21.68	76.19	40.16	3.087	17.09	40.21	1.387	No. Positive	18
	R square	0.2972	0.2788	0.586	0.06604	0.1648	0.1573	0.1797	0.258	0.1408	0.2324	0.1318	0.2773	0.3168	0.6189	0.2313	0.607	0.02836	0.217	No. R^2> 0.4	2
	Sy.x	13.86	1086	8.65	2.639	49.64	9.017	16.84	15.14	6.966	4.506	3.72	7.496	140.6	31.46	4.879	13.39	64.17	2.479		
	P value	**<0.0001**	**<0.0001**	**<0.0001**	**0.026**	**0.0007**	**0.0004**	0.1696	0.0532	**0.0015**	**<0.0001**	**0.0015**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0002**	**<0.0001**	0.2023	**<0.0001**	No. P < 0.05	15
Alkalinity	Slope	1.457	111.2	0.9888	0.1147	0.9676	0.4411	1.486	0.7822	0.4299	0.2835	0.1882	0.1689	14.09	3.161	0.4553	1.606	-0.7589	0.1552	No. Positive	17
	R square	0.5813	0.5661	0.6225	0.132	0.01993	0.151	0.6396	0.3012	0.1833	0.1927	0.1428	0.01461	0.5134	0.5429	0.4431	0.586	0.008898	0.2162	No. R^2> 0.4	8
	Sy.x	10.7	842.5	6.662	2.544	58.71	9.051	9.648	10.31	7.851	5.021	3.99	12	118.7	25.09	4.416	11.67	69.29	2.557		
	P value	**<0.0001**	**<0.0001**	**<0.0001**	**0.0014**	0.227	**0.0006**	**<0.0001**	**<0.0001**	**0.0001**	**<0.0001**	**0.0008**	0.3016	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.4208	**<0.0001**	No. P < 0.05	15
Turbidity	Slope	3.864	292.5	3.657	0.3892	9.93	1.612	5.703	3.801	1.314	0.8085	0.6082	0.9053	39.83	13.05	1.2	5.723	-3.76	0.5277	No. Positive	17
	R square	0.4083	0.3913	0.5387	0.1519	0.2413	0.2016	0.3598	0.2696	0.2318	0.1811	0.173	0.08338	0.4098	0.4778	0.3901	0.5228	0.0266	0.2683	No. R^2> 0.4	5
	Sy.x	12.72	997.8	9.131	2.515	47.31	8.777	14.88	15.02	6.587	4.654	3.63	8.442	130.7	36.83	4.346	14.75	64.23	2.397		
	P value	**<0.0001**	**<0.0001**	**<0.0001**	0.0005	**<0.0001**	**<0.0001**	**0.0392**	**0.0473**	**<0.0001**	**0.0002**	**0.0002**	**0.0197**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.2171	**<0.0001**	No. P < 0.05	16
Conductivity	Slope	0.2831	22.03	0.1934	0.0143	0.5581	0.0963	0.1863	0.1629	0.06988	0.04849	0.03206	0.00248	2.935	0.7493	0.05596	0.3115	-0.3515	0.0328	No. Positive	17
	R square	0.8511	0.8614	0.8961	0.07964	0.2962	0.2791	0.3927	0.4717	0.2679	0.2626	0.1888	0.003083	0.864	0.936	0.3588	0.9212	0.07608	0.4176	No. R^2> 0.4	8

	Sy.x	476.2	4.334	2.62	45.56	8.34	14.49	12.77	6.43	4.416	3.596	8.807	62.75	12.9	4.456	5.996	62.58	2.138			
	P value	**<0.0001**	**<0.0001**	**<0.0001**	**0.0142**	**<0.0001**	**<0.0001**	**0.0292**	**0.0047**	**<0.0001**	**<0.0001**	**0.0001**	0.6936	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0345**	**<0.0001**	No. P < 0.05	17
Hardness	Slope	1.073	82.83	0.6474	0.05537	1.834	0.3147	1.002	0.5755	0.2792	0.1613	0.1089	0.01773	10.6	2.442	0.2545	0.9604	-1.376	0.1133	No. Positive	17
	R square	0.6941	0.6917	0.6554	0.06782	0.1576	0.1693	0.5451	0.3249	0.2473	0.1667	0.1243	0.0007402	0.6398	0.6488	0.4054	0.5714	0.07216	0.2808	No. R^2> 0.4	8
	Sy.x	9.146	710.1	7.892	2.636	49.85	8.953	12.54	14.44	6.52	4.695	3.736	8.814	102.1	30.2	4.291	13.98	62.71	2.376		
	P value	**<0.0001**	**<0.0001**	**<0.0001**	**0.024**	**0.001**	**0.0002**	**0.0061**	**0.0265**	**<0.0001**	**0.0003**	**0.0021**	0.8297	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0397**	**<0.0001**	No. P < 0.05	17
TDS	Slope	41.73	3126	69.52	3.248	103.3	18.03	55.75	40.11	13.25	11.47	6.687	21.68	443.3	270.8	12.33	112.4	-51.86	6.066	No. Positive	17
	R square	0.2972	0.2788	0.586	0.06604	0.1648	0.1573	0.1797	0.258	0.1408	0.2324	0.1318	0.2773	0.3168	0.6189	0.2313	0.607	0.02836	0.217	No. R^2> 0.4	3
	Sy.x	13.86	1086	8.65	2.639	49.64	9.017	16.84	15.14	6.966	4.506	3.72	7.496	140.6	31.46	4.879	13.39	64.17	2.479		
	P value	**<0.0001**	**<0.0001**	**<0.0001**	**0.026**	**0.0007**	**0.0004**	0.1696	0.0532	**0.0015**	**<0.0001**	**0.0015**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0002**	**<0.0001**	0.2023	**<0.0001**	No. P < 0.05	15
Criterium	No. P < 0.05	7	6	7	6	6	7	5	4	7	7	7	4	7	6	7	6	2	7	No. at 6+	14

Table S13. Results of Dunn’s multiple comparisons between water quality criteria and the different sampling regions

	pH	Temperature (°C)	TDS (mg/L)	Conductivity (µg/L)	Turbidity (NTU)	Total Alkalinity ((mg/L)	Total Hardness (mg/L)
Kruskal-Wallis p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Naki vs. Luzira	>0.9999	0.1023	0.2056	0.2757	0.675	>0.9999	0.1944
Naki vs. Gaba	>0.9999	0.9537	0.9908	>0.9999	**0.0027**	**0.0011**	**<0.0001**
Naki vs. Waiya	>0.9999	>0.9999	**<0.0001**	**<0.0001**	0.1101	**<0.0001**	**<0.0001**
Naki vs. Nap	<0.0001	**<0.0001**	**<0.0001**	**<0.0001**	<0.0001	**0.011**	**0.0009**
Naki vs. Thurst	**0.0008**	<0.0001	0.1059	0.0734	**0.0002**	**0.0005**	**0.0405**
Luzira vs. Gaba	>0.9999	>0.9999	>0.9999	>0.9999	0.6592	0.1473	0.135
Luzira vs. Waiya	>0.9999	0.8479	**<0.0001**	**<0.0001**	>0.9999	**<0.0001**	**0.0019**
Luzira vs. Nap	**0.0169**	0.1893	**0.0495**	**0.0377**	**<0.0001**	>0.9999	>0.9999
Luzira vs. Thurst	**0.1331**	**0.0032**	>0.9999	>0.9999	0.2803	0.1483	>0.9999
Gaba vs. Waiya	**>0.9999**	>0.9999	<0.0001	**<0.0001**	>0.9999	0.4759	>0.9999
Gaba vs. Nap	<0.0001	0.0671	**0.0381**	**0.0355**	0.4541	>0.9999	>0.9999
Gaba vs. Thrurst	**0.0012**	**0.0014**	>0.9999	>0.9999	>0.9999	>0.9999	0.2771
Waiya vs. Nap	<0.0001	**<0.0001**	>0.9999	0.8913	**0.0001**	**0.0012**	0.1847
Waiya vs. Thurst	**0.0006**	**<0.0001**	**<0.0001**	**<0.0001**	0.9699	**0.0325**	**0.0043**
Nap vs. Thurst	>0.9999	>0.9999	**0.0412**	**0.0713**	0.1314	>0.9999	>0.9999

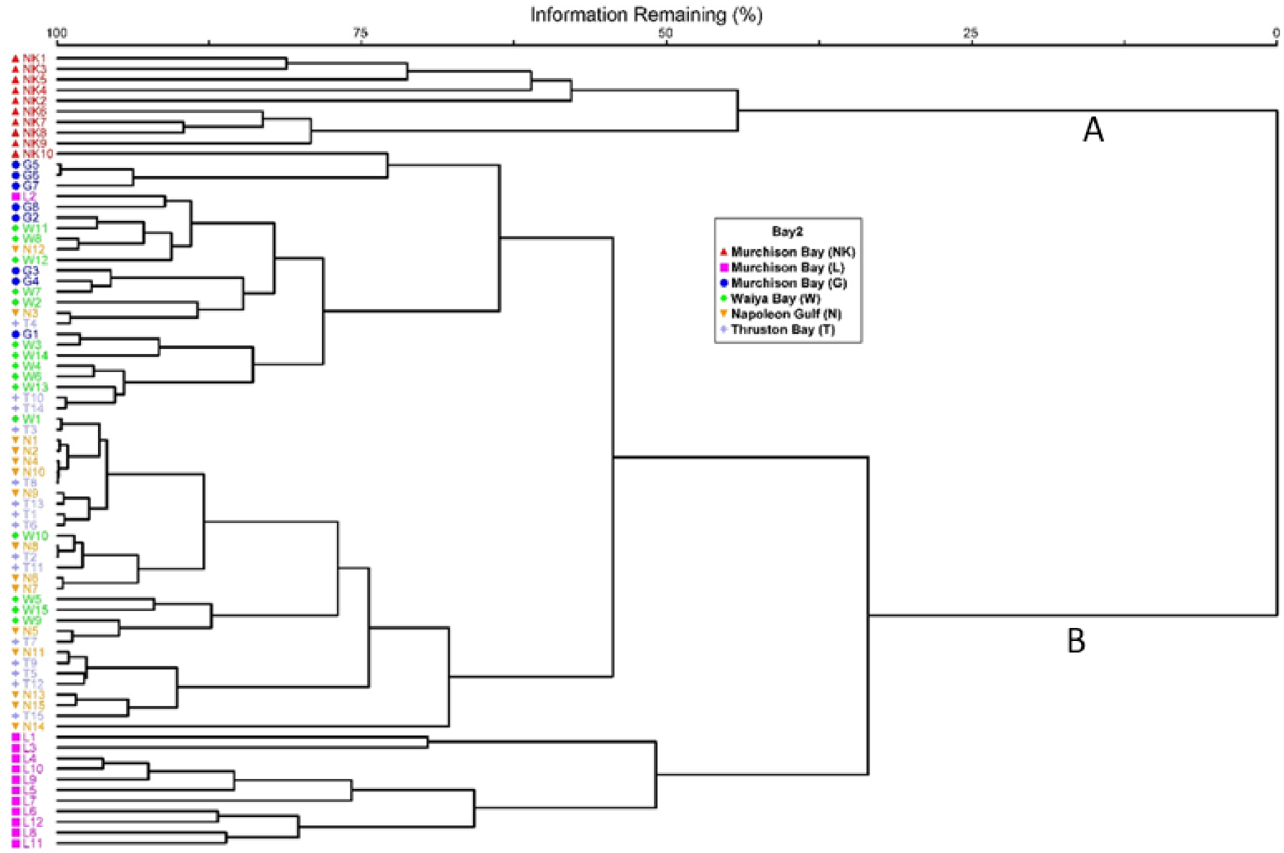

Fig. S2. Hierarchical dendrogram of 75 sampling sites (the distances reflect the degree of correlation between different sampling sites)

Table S14: Concentrations of the target pharmaceutical compounds in the individual samples from different bays of Lake Victoria, Uganda

Murchison Bay

Sampling site 1

Sample No.	NK1	NK2	NK3	NK4	NK5	NK6	NK7	NK8	NK9	NK10
Trimethoprim	64.0	59.9	74.3	89.1	64.4	44.7	42.3	34.1	41.6	26.4
Sulfamethoxazole	4475.8	3908.8	5269.4	5622.0	4040.5	3157.1	2104.4	1826.6	2717.0	1145.6
Sulfamethazine	29.7	30.7	48.3	50.4	26.7	28.9	20.3	20.3	28.8	15.0
Sulfacetamide	5.4	6.5	6.3	6.4	5.5	4.8	4.7	3.9	6.6	2.2
Oxytetracyclin	156.8	302.0	158.6	291.1	100.8	ND	ND	49.0	93.3	ND
Tetracycline	37.9	16.5	9.1	69.7	40.1	10.9	10.1	7.4	11.2	7.2
Erythromycin	53.1	66.1	34.5	33.3	33.7	60.2	40.9	58.7	26.2	37.8
Azithromycin	60.5	56.5	ND	15.4	53.2	16.8	20.0	ND	ND	20.2
Ciprofloxacin	27.8	19.3	33.8	40.6	36.7	24.9	19.5	17.6	20.0	12.4
Levofloxacin	21.2	29.0	20.7	19.4	17.9	25.3	22.9	20.2	18.2	11.4
Norfloxacin	21.6	22.8	14.3	21.9	16.1	20.3	19.3	18.4	15.1	9.4
Enoxacin	32.2	25.0	25.6	28.0	34.3	26.8	28.3	26.1	19.7	18.6
Ibuprofen	519.1	548.9	687.4	714.9	779.9	444.1	335.9	302.4	414.1	242.7
Diclofenac	113.5	115.4	144.6	159.6	140.3	107.9	58.5	58.7	68.5	30.1
Acetaminophen	11.0	27.3	12.9	12.8	20.7	15.6	21.3	12.0	7.5	3.9
Carbamazepine	63.5	51.0	58.8	71.8	59.4	53.4	43.1	37.8	43.1	20.9
Atenolol	23.9	42.7	50.3	ND	ND	38.2	25.4	31.8	ND	34.3
Metoprolol	10.8	7.3	7.8	7.8	21.2	4.8	12.7	2.8	6.0	2.7

Sampling site 2

Sample No.	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
Trimethoprim	12.2	12.4	13.6	13.6	16.7	18.6	14.3	15.4	16.0	14.3	18.4	16.8
Sulfamethoxazole	90.3	121.2	108.2	77.6	108.9	195.9	201.6	194.6	207.7	237.3	263.2	174.1
Sulfamethazine	5.8	5.0	3.4	5.5	4.8	7.2	6.3	7.3	9.6	7.5	8.6	6.3
Sulfacetamide	13.4	1.9	9.3	10.3	8.5	7.5	7.0	9.2	9.1	10.0	10.4	6.3
Oxytetracyclin	149.0	67.7	ND	123.8	139.0	40.4	79.8	129.7	160.2	121.0	38.0	ND
Tetracycline	25.8	13.1	18.4	15.6	12.7	21.2	10.0	9.9	17.9	19.1	15.6	15.7
Erythromycin	10.4	ND	14.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Azithromycin	ND	14.6	ND	ND	16.5	ND	ND	ND	ND	ND	14.9	15.6
Ciprofloxacin	23.8	15.4	32.2	21.8	39.6	21.2	15.9	26.8	25.0	26.7	26.5	30.9
Levofloxacin	11.7	15.0	21.7	10.7	10.6	21.7	ND	18.8	16.9	12.4	25.4	20.3
Norfloxacin	23.0	12.3	19.7	13.6	17.4	17.6	15.0	25.8	14.8	7.8	25.9	20.1
Enoxacin	23.9	40.4	ND	22.4	21.2	29.4	24.1	31.5	34.3	34.6	37.4	48.6
Ibuprofen	36.4	30.7	37.6	61.2	56.7	64.6	53.4	82.0	51.2	40.1	52.3	61.7
Diclofenac	6.6	6.2	6.3	5.7	7.4	7.4	7.1	6.4	6.4	5.1	6.4	8.4
Acetaminophen	8.3	12.2	15.6	10.1	11.9	16.3	14.3	11.5	5.0	10.7	ND	14.7
Carbamazepine	10.1	9.1	8.2	8.6	10.5	10.5	9.1	10.5	9.4	8.9	9.0	10.2
Atenolol	336.6	119.3	384.6	ND	ND	131.6	ND	164.7	80.8	72.1	59.7	ND
Metoprolol	5.3	2.2	8.1	2.8	3.5	2.6	ND	3.0	ND	3.7	4.3	3.4

Sampling site 3

Sample No.	G1	G2	G3	G4	G5	G6	G7	G8
Trimethoprim	15.5	12.3	16.3	15.4	12.0	9.5	13.6	13.2
Sulfamethoxazole	93.7	92.4	102.4	95.1	104.7	105.3	114.0	81.8
Sulfamethazine	2.9	4.5	2.4	2.5	7.6	7.9	8.1	7.7
Sulfacetamide	3.5	10.0	4.3	4.1	4.3	3.3	4.4	4.4
Oxytetracyclin	89.6	46.1	77.6	54.1	62.9	76.4	ND	ND
Tetracycline	11.3	9.1	5.5	13.5	6.0	8.5	13.8	15.7
Erythromycin	ND	ND	ND	ND	ND	ND	ND	ND
Azithromycin	ND	14.4	ND	ND	ND	ND	ND	16.3
Ciprofloxacin	12.7	14.9	21.3	20.8	14.1	18.2	17.6	14.0
Levofloxacin	23.1	15.6	12.7	19.5	15.5	15.8	26.0	12.8
Norfloxacin	18.0	16.1	14.9	11.6	17.3	18.7	16.8	13.2
Enoxacin	50.7	28.2	28.9	30.1	22.9	23.4	28.0	29.2
Ibuprofen	38.1	57.7	35.9	45.0	131.6	113.8	111.0	105.5
Diclofenac	3.7	2.2	2.0	1.8	24.3	23.0	22.9	23.6
Acetaminophen	2.9	5.3	3.2	ND	ND	2.4	ND	6.3
Carbamazepine	6.7	5.1	4.8	5.3	29.3	26.0	26.8	29.5
Atenolol	58.7	129.2	ND	41.5	ND	ND	ND	106.4
Metoprolol	3.8	3.1	ND	3.8	5.9	6.2	5.6	4.4

Waiya Bay

Sample No.	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Trimethoprim	8.0	10.3	10.3	10.1	7.2	9.4	10.5	10.0	10.5	10.3	10.9	11.5	9.4	8.9	10.2
Sulfamethoxazole	4.1	7.2	4.2	7.6	5.0	4.3	5.1	5.4	4.2	4.0	5.9	4.6	6.0	6.1	9.0
Sulfamethazine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.6	ND	ND
Sulfacetamide	1.8	3.2	2.5	2.6	2.5	1.9	1.6	1.3	3.4	2.9	5.4	3.1	3.6	3.5	3.6
Oxytetracyclin	51.2	ND	94.4	193.9	79.1	125.9	106.8	75.9	103.6	40.9	74.7	131.0	137.7	133.2	ND
Tetracycline	15.4	4.6	11.8	9.9	5.7	12.7	13.7	6.4	5.3	3.2	7.7	5.1	4.0	24.7	12.9
Erythromycin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Azithromycin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ciprofloxacin	17.7	15.9	12.1	10.7	14.1	11.4	20.0	10.7	20.9	18.4	12.9	16.3	13.8	12.8	14.9
Levofloxacin	9.3	11.2	14.3	16.2	14.1	20.6	11.7	15.4	14.1	11.6	13.0	13.4	14.3	11.7	14.9
Norfloxacin	12.4	13.9	16.5	14.1	11.8	16.7	10.7	14.2	10.2	12.1	16.6	13.5	12.0	9.9	12.7
Enoxacin	22.5	51.4	43.2	25.5	ND	26.4	29.3	29.3	ND	14.9	24.6	28.8	24.0	41.4	ND
Ibuprofen	45.5	45.0	46.6	59.6	50.7	43.3	43.9	57.7	54.9	54.6	50.0	48.3	48.8	46.0	61.3
Diclofenac	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetaminophen	5.8	ND	3.4	7.9	ND	3.1	ND	ND	7.3	ND	ND	4.9	ND	5.2	ND
Carbamazepine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Atenolol	94.8	ND	77.7	46.8	ND	53.3	44.5	106.7	123.4	38.7	110.6	219.8	ND	64.0	133.1
Metoprolol	4.0	2.7	4.6	3.9	ND	2.9	4.0	4.4	3.3	2.5	3.2	4.2	3.3	3.3	2.8

Napoleon Gulf

Sample No.	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15
Trimethoprim	6.7	6.3	7.1	8.8	8.9	12.5	9.4	12.7	8.0	8.5	12.2	7.8	9.1	9.8	9.6
Sulfamethoxazole	5.5	4.4	4.7	4.7	3.7	5.8	4.3	4.2	4.4	4.5	3.8	3.7	3.0	2.9	3.2
Sulfamethazine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sulfacetamide	2.6	1.4	2.1	2.1	2.1	4.2	3.9	2.4	1.6	2.1	1.8	2.0	1.6	1.5	2.5
Oxytetracyclin	44.0	100.8	16.8	60.4	66.3	84.3	61.1	56.2	74.8	62.6	91.3	46.1	36.0	45.5	32.3
Tetracycline	2.9	4.7	3.2	4.2	4.8	9.4	8.9	7.7	5.1	2.7	7.1	9.7	2.7	13.1	8.6
Erythromycin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Azithromycin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ciprofloxacin	11.0	13.3	11.7	15.3	16.3	12.2	12.6	10.9	14.0	11.1	ND	16.2	ND	12.8	ND
Levofloxacin	11.2	10.6	13.0	11.8	ND	9.7	10.8	10.3	10.3	8.6	10.3	15.6	11.4	ND	9.3
Norfloxacin	13.5	13.9	11.9	13.5	14.8	13.2	12.3	14.6	9.6	12.5	10.2	11.7	11.1	ND	8.1
Enoxacin	17.5	20.2	35.0	15.4	ND	16.2	14.8	17.9	14.8	15.0	15.5	21.5	ND	ND	ND
Ibuprofen	37.7	38.9	26.4	41.1	34.7	38.8	26.6	32.1	37.5	22.8	23.4	33.2	21.2	25.3	26.9
Diclofenac	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetaminophen	3.4	3.6	5.8	ND	5.8	7.2	ND	ND	5.8	3.6	ND	ND	ND	6.4	2.6
Carbamazepine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Atenolol	64.1	71.7	28.3	108.9	107.8	168.0	167.5	63.4	80.5	109.0	80.0	117.5	97.8	97.1	59.9
Metoprolol	2.6	2.8	2.8	2.8	2.8	2.6	2.8	3.1	3.3	2.8	2.2	3.7	2.2	2.9	3.5

Thurston Bay

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
Trimethoprim	8.5	10.4	10.2	9.3	7.7	10.6	10.3	8.6	9.4	10.1	10.7	10.2	10.3	9.7	10.2
Sulfamethoxazole	3.8	3.2	2.6	3.0	2.9	2.8	3.3	3.9	2.4	3.9	5.1	3.7	3.0	3.0	3.4
Sulfamethazine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sulfacetamide	2.7	2.8	1.0	2.0	1.8	3.0	2.4	2.0	2.9	1.9	4.9	3.1	1.9	1.7	2.2
Oxytetracyclin	86.4	63.6	71.0	34.0	35.5	99.2	45.1	104.6	54.0	162.2	44.4	109.1	103.0	110.6	155.2
Tetracycline	8.6	7.5	11.8	3.9	4.5	3.1	5.8	3.4	4.9	11.9	11.1	11.5	11.4	7.7	5.6
Erythromycin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Azithromycin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	15.2	14.4	ND	ND	ND
Ciprofloxacin	11.3	13.3	17.2	12.4	ND	13.2	16.6	15.3	ND	11.3	10.8	ND	15.1	11.5	ND
Levofloxacin	12.7	10.6	8.4	12.7	12.5	16.0	11.6	8.7	9.6	9.3	11.5	14.1	9.8	9.3	11.1
Norfloxacin	11.6	16.3	13.3	6.5	11.4	12.3	14.8	13.8	13.7	9.5	12.2	12.1	11.0	14.8	14.6
Enoxacin	21.2	15.9	20.4	25.4	25.0	19.0	ND	16.2	16.1	22.7	18.0	20.7	15.2	23.4	ND
Ibuprofen	41.7	36.5	34.9	39.7	30.3	40.4	33.7	31.7	31.6	32.4	32.5	33.3	32.9	28.0	21.0
Diclofenac	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetaminophen	6.3	ND	3.3	4.4	3.1	7.3	6.3	4.1	3.2	2.6	ND	3.5	9.6	ND	3.3
Carbamazepine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Atenolol	91.9	35.2	84.6	ND	88.5	114.2	138.7	102.6	69.9	86.1	ND	71.1	93.0	79.5	45.3
Metoprolol	4.5	3.2	2.6	3.5	3.9	3.1	3.6	2.7	2.8	3.8	3.3	3.4	4.0	4.0	2.9

Table S15: Name, type, quality, provider, City and Country of Origin for the standards, consumables and solvents

Name	**Quality**	**Provider**	**City and Country of Origin**
Reference standards (crystalline form)			
Trimethoprim	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Sulfamethoxazole	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Sulfamethazine	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Sulfacetamide	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Oxytetracycline	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Tetracycline	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Erythromycin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Azithromycin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Roxithromycin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Ciprofloxacin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Levofloxacin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Norfloxacin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Sparfloxacin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Enoxacin	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Metronidazole	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Ibuprofen	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Diclofenac	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Acetaminophen	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Carbamazepine	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Diazepam	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Fluoxetine	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Atenolol	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Metoprolol	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Bezafibrate	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Isotope-labelled internal standards (crystalline form)			
Trimethoprim-d_3	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Sulfamethoxazole-d_4	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Thiabendazole-d_4	SRM	Toronto Research Chemicals Inc.	North York, Ontario, Canada
Erythromycin-^{13}C-d_3	SRM	Toronto Research Chemicals Inc.	North York, Ontario, Canada

Ciprofloxacin-d_8	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Ibuprofen-d_3	SRM	Toronto Research Chemicals Inc.	North York, Ontario, Canada
Diclofenac-d_4	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Carbamazepine-d_{10}	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Fluoxetine-d_5	SRM	Toronto Research Chemicals Inc.	North York, Ontario, Canada
Atenolol-d_7	SRM	Dr. Ehrenstorfer GmbH	Augsburg, Germany
Solid phase extraction (SPE) cartridges			
Chromabond HR-X	3 mL (200 mg)	Macherey-Nagel GmbH & Co. KG	Düren, Germany
Solvents			
Methanol Acetonitrile	HPLC-gradient grade	VWR international BDH Prolabo Chemicals	Darmstadt, Germany
Methyl tertiary-butyl ether solvent	HPLC-gradient grade	Merck KGaA	Darmstadt, Germany
Other consumables			
Formic acid	98-100%	Merck KGaA	Darmstadt, Germany
Disodium ethylenediamine tetraacetate (Na_2EDTA) Sodium hydroxide	Analytical grade	Merck KGaA	Darmstadt, Germany
Nitrogen gas	99.999%	Air Products GmbH	Hattingen, Germany

SRM- Standard Reference Material

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