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Status of pharmaceuticals in the Korle Lagoon and their toxicity to non-target organisms

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Abstract

The availability of pharmaceutically active compounds (PhACs) in surface waters and suspended solids/sediments presents an ecological hazard of chronic exposure to non-target organisms. Thus, water and sediment samples were collected from the Korle Lagoon in the west of Accra-Ghana city center to evaluate 35 medicinal drugs belonging to the main therapeutic classes and their toxicity to non-target organisms (i.e., fish, daphnid, and algae). High-performance liquid chromatography coupled to mass spectrometry (HPLC-MS/MS) was employed to analyze the levels of PhACs in the samples. PhACs levels in water samples were higher compared to PhACs levels in sediment samples. Acetaminophen, ibuprofen, tramadol, and Diclofenac were the PhACs that showed a higher frequency of detections and higher average concentrations. Diazepam, mefenamic acid, indomethacin, gemfibrozil, and glibenclamide exhibited a higher frequency of detections, but their average concentrations in both sample types were lower. The calculated risk index values for acetaminophen and ibuprofen suggested low ecological risks to fish, while tramadol showed medium to high ecological risks to daphnid. In contrast, acetaminophen and fenofibrate showed low ecological risks to daphnid. Additionally, the risk index values for fenofibrate suggested medium to high ecological risks to algae, while tramadol exhibited low ecological risks to algae. The other PhACs showed negligible ecological risks to non-target organisms. The calculated toxic unit values for each sampled site suggested a medium adverse ecological risk to non-target organisms. Based on the results obtained, the availability of PhACs in the studied area will have adverse effects on studied non-target organisms. The negative impacts of PhACs on non-target organisms may cause an imbalance in the food chain process, leading to a decrease in fish production and a reduction in fish quality. The result of this study is evidence of public health threat because the accumulation of PhACs in fish species may also cause some kinds of hormonal, chemical, and molecular changes within the various systems of the fishes to be toxic or unpleasant for humans' consumption.

Keywords Pharmaceutically active compounds · Eco-toxicological data · Environmental risk assessment · Lethal concentration · Effect concentration · Korle Lagoon

Introduction

In addition to the primary contaminants such as heavy metals, polychlorinated biphenyls, pesticides, aliphatic and polycyclic aromatic hydrocarbons, etc. which are threatening the environment, the so-called unregulated emerging pollutants are gaining grounds in environmental contamination (da Silva et al. 2011; Asare 2016; Molnar et al. 2020; Asare 2021). Emerging contaminants are artificial or naturally occurring chemicals or microbes that are not regularly monitored in the environment but can enter and result in known or believed unfavorable environmental effects (da Silva et al. 2011). Generally, these chemicals manufactured commercially have many uses and are essential to our present-day society. Among these numerous

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emerging contaminants, pharmaceuticals are finding their way into the entire ecological compartment.

Pharmaceuticals are different classes of compounds designed to cure or treat illness and enhance health. Pharmaceuticals have improved in recent decades, promoting the increase of mean age, growth and well-being of people (Guzel et al. 2019). The usage of pharmaceuticals has increased remarkably. Technologies for wastewater treatment are not feasible and efficient for detaching all sorts of pharmaceutically active compounds (PhACs) with the same competence. Thus, most PhACs with their metabolites and conjugates have emerged in every corner of ecological partitions (i.e., biota, surface waters, sediment, etc.) (Halling-Sorensen et al., (1998); Kummerer 2004; Molnar et al. 2020). The study of medicine's effects on humans is through safety and toxicology research; the likely ecological impacts of their presentation and usage are not much recognized and have raised an issue of concern (Boxall 2004). In addition, knowledge regarding the potential adverse health impacts of PhACs on non-target organisms such as phytoplankton, zooplankton, crustaceans, mollusks, and fish when the various PhACs combine in complex mixtures in aquatic environments is inadequate (Guzel et al. 2019). Komori et al. opined that quantification and hazard evaluation of PhACs in the environment is on individual compounds (Komori et al. 2013). However, PhACs do not always occur as isolated matter in the environment (Komori et al. 2013; Molnar et al. 2020). Thus, to get a logical overview of environment involvement and exploration, evaluation of multicomponent mixture effect of PhACs is needed (Heys et al., (2016)). Also, the actual elucidation of measured environmental concentration (MEC) of PhACs is a problem for researchers (Guzel et al. 2019). The availability of data on empirical toxicity of PhACs such as no observed effect concentration (NOEC), median effective concentration (EC_{50}), and median lethal concentration (LC_{50}) is lacking, and on condition that such information is available; their descriptions are from different observations. For example, other species and different endpoints, so, that is to say, they are inconsistent (Guzel et al. 2019). A hazard quotient (RQ) is applied to evaluate the potential risk of PhACs in any environmental media. RQ is the rate of the maximum MEC to the predicted no-effect concentrations (PNEC). In this context, the PNEC depends on the available toxicological data (Komori et al. 2013; Molnar et al. 2020).

In recent times, Ghana has raised its stand in the African pharmaceutical market and utilization (Ghana Pharmaceutical report 2012). Such high utilization may result in the verdict that the problem relating to aquatic pollution by PhACs could be a critical concern, and thus PhACs in water bodies must be evaluated. Additionally, because data are unavailable on the pollution levels of PhACs in Ghanaian aquatic ecosystems, it is necessary to establish a hierarchy of national rivers or lagoons for the investigation of PhACs. One of the coastal wetlands in Ghana is Korle Lagoon which consists of an open lagoon, salts pans, marsh, beautiful dunes, and scrubs. It is in the north-eastern portion of Agbogbloshie town in which one of Ghana's largest dumping sites is located. The lagoon flows from the west center of Accra and joins the coast of the Gulf of Guinea. In the 1990s, the administration of Ghana set up the Korle Lagoon ecological restoration project, intending to reinstate the lagoon to a more natural condition and lessen contamination (Boadi and Kuitunen 2002), but an unplanned encampment, Old Fadama, was created by some 70,000 citizens on the banks of the lagoon. The current state of the lagoon is an eyesore. The lagoon is polluted with different forms of waste by the influence of anthropogenic activities.

Furthermore, researchers focused only on heavy metals in and around the lagoon (Boadi and Kuitunen 2002; Fosu-Mensah et al. 2017), but information regarding PhACs levels in water and surface sediments of the lagoon and their toxicity to non-target organisms are lacking. For these reasons, this work aimed to examine the status and environmental risk assessment of PhACs in water and surface sediments collected from the Korle Lagoon. Hence, treated samples were analyzed to evaluate 35 pharmaceuticals belonging to the various therapeutic classes such as antidiabetics, psychiatric drugs, antibiotics, analgesics, and anti-inflammatory drugs, ß-blockers, anti-ulcer agent, cholesterol-lowering statin, lipid regulator drugs, and diuretics and their potential risk to non-target organisms (i.e., fish, daphnid, and algae).

Materials and methods

Chemicals

Pharmaceutical standards with a high purity grade (>90%) were used to identify target compounds. Diclofenac, naproxen, gemfibrozil, ibuprofen, and ketoprofen were purchased from Jesuder, Rubi, Spain. Butalbital, lorazepam, and diazepam were supplied by Cerilliant, Texas, USA. Atorvastatin was purchased from LGC Promochem, London, UK. Mevastatin, indomethacin, phenazone, acetaminophen, fenofibrate, mefenamic acid, famotidine, bezafibrate, cimetidine (hydrochloride), josamycin, azithromycin (dehydrate), ranitidine (hydrochloride), tyrosine A., carbamazepine, tramadol, chloramphenicol, metronidazole, erythromycin (hydrate), clarithromycin, pravastatin (sodium salt), trimethoprim, furosemide, nadolol, glibenclamide, atenolol, and hydrochlorothiazide were received from Sigma-Aldrich, Steinheim, Germany.

The internal standards (IS) used were isotopically labeled compounds. They include erythromycin-$^{13}C,d_3$ (N-Methyl-^{13}C,

d_3), diclofenac-d_4, rac-naproxen-d_3, gemfibrozil-d_6, ibuprofen-d_3, ketoprofen-$^{13}CD_3$, diazepam-d_5, acetaminophen-d_4, atorvastatin-d_5 sodium salt, pravastatin-d_3, metronidazole hydroxyl-d_2, bezafibrate-d_4, hydrochlorothiazide-3,3-d_2, and fenofibrate-d_6 from Ghana Food and Drugs Authority. Solvents, acetonitrile, HPLC grade methanol, formic acid, and water (Lichrosolv) were provided by Merck, Darmstadt, Germany. Sankofa Ghana Air Liquid supplied nitrogen gas (99.995% purity) for drying.

Sample collection

Korle Lagoon is 104 m above sea level with the coordinate 5°33'0″N and 0°13'0″W. Water and surface sediment samples were collected in February 2021 (Fig. 1). For easy identification, samples were labeled based on the type of sample medium collected. That is, KLW signifies water samples and KLS denotes surface sediment samples. The protocol for collecting water samples was adapted by Molnar et al. (2020). Water-column sample devices were used to collect the water samples from the middle of the water in 1.5 L glass bottles with Teflon-faced caps. A total of 10 samples were collected from 10 sampling sites. A pure formic acid was used to acidify each liter of sample to reduce the pH to 3.5–4.0 due to sorbent type compatibility. Samples were stored in an ice chest at a temperature of 6 °C and transported to the laboratory within 72 h.

The protocol for collecting surface sediments from the lagoon was adapted by da Silva et al. (2011). A grab sampler was used to collect the surface sediments (0–5 cm). Ten surface sediment samples were grabbed, placed in polyethylene bags, and kept in an ice chest at a temperature of 50 °C. The samples were transported to the laboratory within 48 h. In the laboratory, sediment samples were preserved at 15 °C and later freeze-dried for 72 h. The freeze-dried samples were ground using mortar and pestle, sieved through a 125 µm plastic sieve, and homogenized. The powdery samples were stored in pre-cleaned plastic bottles in a refrigerator at 25 °C before extraction.

Preparation of standard solutions

Each standard solution and isotopically labeled internal standard solutions were prepared based on mass in CH_3OH. Diazepam and lorazepam were dissolved in CH_3OH at a concentration of 1 mg/mL. Furosemide was obtained as a solution in acetonitrile. The solutions were kept in a refrigerator at 25 °C. Because of the limited stability of fresh stock solutions of antibiotics, they were prepared monthly. The rest of the stock solutions were restored every 120 days. All medicines were prepared using a suitable dilution factor for each stock solution in a mixture of CH_3OH and H_2O (1:3, v/v), and after each analytical run, they were renewed. Also, a different combination of an isotopically labeled internal standard used for internal standard measurement was prepared in CH_3OH and then diluted in a mixture of CH_3OH and H_2O (1:3, v/v).

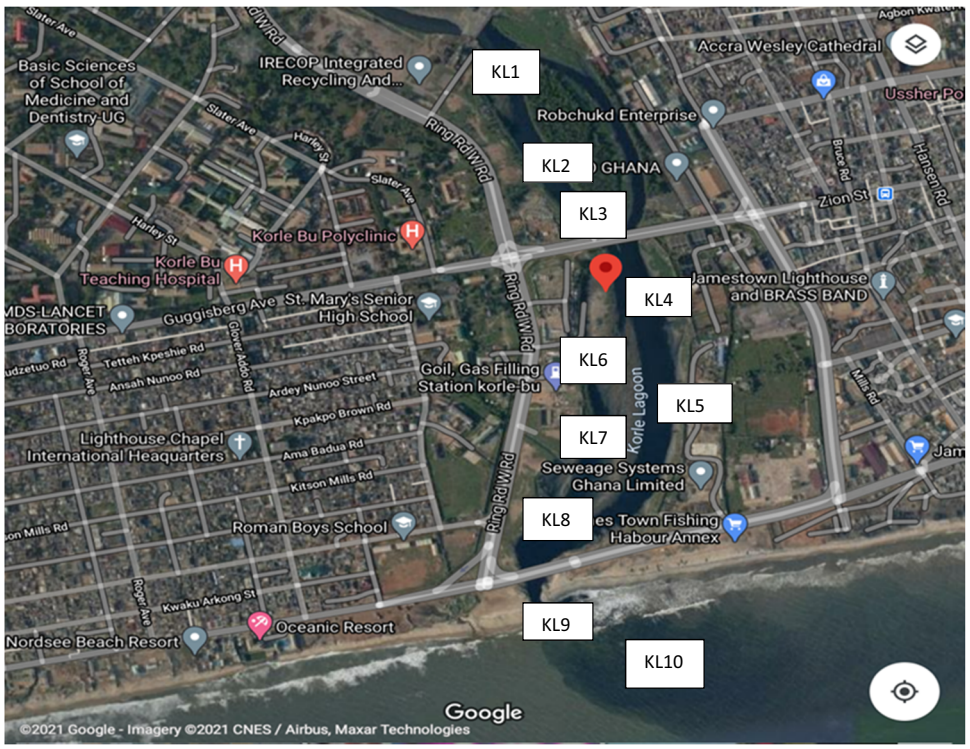

Fig. 1 Satellite map of the study area showing sampled sites

Sample preparation

Techniques for water and surface sediment samples preparation before analyses were adapted by Gros et al. (2009).

Surface sediment samples

Approximately 1.5 g of surface sediment sample was measured and extracted using the pressurized liquid extraction technique. The extraction solvents (i.e., a mixture of CH_3OH and H_2O in a ratio of 1:2) were used to perform the extractions at 100 °C and 1500 psi in three static cycles, each withstanding 150 s. The extraction cell was washed with 100% cell volume of fresh solvent. The extracts were diluted with water and processed as water samples to lessen the concentration of CH_3OH (<5 vol %).

Water samples

The extraction of compounds of interest from water samples was carried out using a solid-phase extraction technique. Pure methanol (2 × 4 mL) was used to perform the elution. The eluents were evaporated by a stream of nitrogen and restored in their former conditions by adding a mixture of CH_3OH and H_2O (1:3, v/v). Before analysis, the extracts were enhanced with a combination of internal standards to a final concentration of 15 ng/mL. Each sample was extracted and analyzed three times.

Instrumental analysis

High-performance liquid chromatography coupled to mass spectrometry (HPLC-MS/MS) using a technique adapted by Gros et al. (2009) was employed to analyze PhACs in the samples. In brief, liquid chromatography was carried out using Symbiosis™ Pico, stocked with an autosampler, and joined in series to a 4000 QTRAP mass spectrometer stocked with a Turbo Ion Spray source. A Purospher Star RP-18 column (125 mm × 2 mm, particle size five µm) was used to achieve chromatographic separation. Eluent A (i.e., a mixture of C_2H_3N-CH_3OH 50%:50% v/v) and eluent B (HPLC grade water) were used as the mobile phases for the analysis in negative ionization (NI) mode. The positive ionization (PI) mode analysis was conducted using C_2H_3N as eluent A and HPLC grade water with 0.2% formic acid as eluent B. The compounds of interest were analyzed in MRM mode, checking two transitions between the most abundant fragment ions and the precursor ion for the individual compound. Detailed information concerning the operation of the HPLC-MS/MS technique to analyze PhACs in water and sediment samples can be obtained from other related works [Gros et al. (2009) for water samples; Jelic et al. (2009) for solid samples].

Environmental risk assessment (ERA)

Predicted no-effect concentrations (PNEC)

Environmental risk assessment is dependent on ecotoxicological threshold data from experiments on aquatic organisms (fish species, daphnid, and or algae). Thus, the values for NOEC and E(L)C50 obtained from chronic and acute tests, respectively, are considered. Applying the NOEC and E(L)C50 values, the species sensitivity distribution curve (SSD) and the risk concentrations (HC) of a given species can be calculated. For example, HC5, which means 5% of the species in the species sensitivity distribution curve, shows an effect can be deduced using the CAFE database and software. The predicted no-effect concentrations (PNEC) can be computed using Eq. 1;

$$\mathrm{PNEC} = \frac{\mathrm{NOEC\ or\ E(L)C50\ or\ HC5}}{\mathrm{AF}} \quad (1)$$

The extent of the assessment factor (AF) depends on the available data on toxicity. The PNEC values increase depending on toxicological information for aquatic organisms obtainable at several feeding levels. Also, the value of AF decreases in situations of significant and vital datasets. For example, an AF of 1000 is used when the data on toxicity is only obtainable depending on E(L)C50, but an AF of 100 is used when NOEC is obtained from tests with one trophic level (e.g., fish). In addition, AF equal to 10 is used when NOEC is known for all three trophic levels (Hamre 2006; Molnar et al. 2020). AF is equal to 5 when dealing with five or more different species (separately on trophic levels) with the same data on toxicity, which means the value of HC5 is known. According to Sanderson et al. (2004), the predicted E(L)C50 values reported by US-EPA Structure-Activity Relationships Class Program (ECOSAR database) are mainly employed on the condition that no data on toxicity are available. Although the data on toxicity from the ECOSAR database are immensely in doubt, the acceptable AF value is 1000 (Zhang et al. 2017).

Risk quotient (RQ)

Environmental risk assessment can be characterized after quantifying the PhaACs concentrations in water and surface sediment samples and determining their toxicology threshold values. RQ of each PhaACs in each sample was calculated using Eq. 2;

$$\mathrm{RQ} = \frac{\mathrm{Maximum\ MEC}}{\mathrm{PNEC}} \quad (2)$$

Generally, $\mathrm{RQ} < 0.01$ signifies a negligible risk, $\mathrm{RQ} < 0.1$ indicates a low risk, $0.1 > \mathrm{RQ} < 1.0$ denotes a medium risk, and $\mathrm{RQ} > 1.0$ suggests high ecological risks to

the aquatic organism (EU Commission 2003; Ma et al. 2016).

Toxic unit (TU)

The degree of a mixture of pharmaceuticals that can harm the non-target organisms can be evaluated by adding the concentration (CA) model and ignoring the toxic modes of action of the mixture constituents when dealing with a vast number of aquatic mixture toxicity studies (Molnar et al. 2020). The concentration addition model suggests that the contribution of the individual toxicants to the total effect can be added in the form of toxicant units (De Zwart, Posthuma (2005)). In this study, the concentration addition of PhaACs was expressed by Eq. 3 (Molnar et al. 2020);

$$\mathrm{TU} = \sum_{i=1}^{n} \frac{\mathrm{MEC_i}}{\mathrm{E(L)C50_i\,or\,NOEC_i}} \quad (3)$$

where MEC_i represents the actual concentration, $E(L)C50_i$ or $NOEC_i$ represents the exposure concentrations of a given PhaACs that can trigger the same toxicity response for all compounds. The TU has only one threshold and is a dimensionless expression, and if its value is >1.0, then a potential risk is anticipated.

Results

Status of pharmaceuticals in water and surface sediment samples

Table 1 shows the average concentrations of thirty-five pharmaceuticals detected in water and surface sediment samples. Table S1 depicts average concentrations and standard deviations (SDs) of PhaACs levels detected (See supplementary material).

The degree to which the PhaACs in the water samples are dispersed is below 7% (Table S1). The occurrence pattern of each PhACs detected in water samples is similar to each PhACs detected in sediment samples with few exceptions (Table 1). Concerning water samples, the PhACs that exhibited a higher average concentration and frequency of detection include acetaminophen with the maximum average concentration of 2987.91 ng/L in a water sample from sampled site KL_{W9} and 2622.35 ng/L in a water sample from sampled area KL_{W1}, Ibuprofen with a maximum average concentration of 105.39 ng/L in a water sample from sampled site KL_{W9}. Tramadol with a maximum average concentration of 105.11 ng/L in a water sample from sampled site KL_{W6}, and Diclofenac with a maximum average concentration of 100.91 ng/L in a water sample from sampled area KL_{W8}. Furosemide showed a higher average concentration of 157.89 ng/L in a water sample from sampled site KL_{W9}. Also, ß-blocker atenolol exhibited a higher average concentration of 86.35 ng/L in a water sample from sampled area KL_{W8}.

Other PhACs detected in almost all water samples include atorvastatin (a cholesterol-lowering statin drug), bezafibrate (lipid regulator), and azithromycin (an antibiotic). Surprisingly, diazepam, which belongs to the benzodiazepine family that acts as an anxiolytic, was detected in all water samples and its concentrations were relatively high. Carbamazepine, an anticonvulsant medication used primarily to treat epilepsy and neuropathic pain, was detected in most downstream sampled sites, but the concentrations were insignificant. Chloramphenicol drug, which belongs to an antibiotic class of medicine for the treatment of several bacterial infections, was detected in most samples collected from upstream and near the coastal area of the Gulf of Guinea, although the concentrations were not high. An antibiotic drug called clarithromycin, which treats strep throat, pneumonia, skin infections, Lyme disease, etc., was detected in some water samples collected downstream with significant concentrations. Gemfibrozil drug associated with diet to reduce the amount of cholesterol and triglycerides in the blood was detected in almost all sampled sites; however, its concentrations were insignificant. Ketoprofen which possesses analgesic and antipyretic effects was observed in samples collected from upstream. However, the concentrations were not high (Table 1). Indomethacin, which reduces fever, pain, stiffness, and swelling from inflammation, was detected in some sampled sites; nevertheless, its concentrations were insignificant. High levels of mefenamic acid medicine were detected in upstream sampled areas. However, the concentrations detected in downstream sampled sites were below the limit of quantitation (LOQ). Phenazone and ranitidine were found in upstream sampled sites. Comparatively, the levels of ranitidine in water samples detected were higher than the levels of phenazone observed in water samples. Tyrosine A was noticed only in midstream sampled sites; however, the contents were insignificant. Tramadol and diazepam were the only PhACs detected in all water samples. No observation of metronidazole in any of the water samples.

The dispersion of PhaACs in surface sediment samples is lower than 8% (Table S1). In sediment samples, there is an observation of higher average concentrations of acetaminophen with 105.11 ng/g in a sediment sample from sampled station KL_{S1}, ibuprofen with 69.21 ng/g in a sediment sample from sampled station KL_{S9}, and tramadol with 56.82 ng/g in a sediment sample from sampled station KL_{S8}. Pharmaceuticals such as bezafibrate, ranitidine, atorvastatin, ketoprofen, indomethacin, and diazepam were higher in some of the sediment samples (Table 1). Atenolol, clarithromycin, fenofibrate, gemfibrozil, josamycin, mefenamic acid, nadolol, and tyrosine A were detected at lower levels in all sediment samples. No detection of metronidazole, trimethoprim,

Table 1 Average concentrations of pharmaceutically active compounds (PhACs) in water and sediment samples from Korle Lagoon, analysis performed in triplicate (ng/L for Conc. in water and ng/g for Conc. in sediment)

PhACs	Sampled point									
Water samples	KL_{W1}	KL_{W2}	KL_{W3}	KL_{W4}	KL_{W5}	KL_{W6}	KL_{W7}	KL_{W8}	KL_{W9}	KL_{W10}
Anti-diabetics										
Glibenclamide	N.D	N.D	N.D	N.D	N.D	14.05	16.27	16.05	9.33	4.91
Psychiatric drugs										
Diazepam	11.02	9.44	16.10	5.77	5.71	18.81	18.96	10.85	19.07	6.01
Lorazepam	N.D	N.D	N.D	N.D	N.D	<LOQ	<LOQ	<LOQ	4.02	<LOQ
Antibiotics										
Azithromycin	<LOQ	<LOQ	<LOQ	12.61	13.22	N.D	N.D	N.D	10.46	<LOQ
Chloramphenicol	41.36	25.08	16.51	11.04	6.09	<LOQ	<LOQ	<LOQ	7.22	2.91
Clarithromycin	<LOQ	<LOQ	<LOQ	N.D	N.D	22.10	23.67	20.21	29.11	12.30
Erythromycin	N.D	N.D	N.D	N.D	N.D	<LOQ	<LOQ	<LOQ	5.12	<LOQ
Josamycin	N.D	N.D	N.D	N.D	N.D	3.05	2.15	<LOQ	<LOQ	<LOQ
Metronidazole	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Tylosine A	<LOQ	<LOQ	<LOQ	<LOQ	4.11	3.05	N.D	N.D	<LOQ	N.D
Trimethoprim	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Analgesics & anti-inflammatory										
Acetaminophen	2622.35	96.81	61.10	188.72	173.50	40.41	<LOQ	<LOQ	2987.91	<LOQ
Butalbital	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Carbamazepine	N.D	N.D	N.D	<LOQ	<LOQ	6.91	10.10	8.31	6.44	<LOQ
Diclofenac	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	n.d	100.91	44.01	4.51
Ibuprofen	88.71	56.25	31.81	55.14	27.77	<LOQ	12.11	9.45	105.39	9.03
Indomethacin	11.01	6.13	5.84	<LOQ	4.66	<LOQ	N.D	N.D	4.01	<LOQ
Ketoprofen	26.05	13.77	6.02	8.09	<LOQ	N.D	N.D	N.D	<LOQ	N.D
Mefenamic acid	4.17	6.93	7.44	2.41	3.62	<LOQ	<LOQ	<LOQ	2.03	<LOQ
Naproxen	N.D	8.02	<LOQ	<LOQ	3.15	N.D	N.D	N.D	2.07	N.D
Phenazone	6.19	11.58	4.06	<LOQ	<LOQ	N.D	N.D	N.D	3.38	<LOQ
Tramadol	5.01	9.17	5.91	11.02	8.51	105.11	70.14	42.51	27.12	4.59
β-blockers										
Atenolol	<LOQ	<LOQ	N.D	N.D	N.D	19.95	49.48	86.35	16.11	N.D
Nadolol	N.D	N.D	N.D	<LOQ	7.06	N.D	N.D	N.D	4.61	2.09
Anti-ulcer agents										
Cimetidine	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	N.D	N.D	5.71	<LOQ
Famotidine	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	6.04	7.11	4.07	<LOQ
Ranitidine	22.91	16.04	9.25	10.31	<LOQ	N.D	N.D	N.D	<LOQ	<LOQ
Cholesterol-lowering statin										
Atorvastatin	12.52	20.04	<LOQ	<LOQ	N.D	33.81	40.01	16.04	15.11	<LOQ
Mevastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	<LOQ	<LOQ	<LOQ
Pravastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Fenofibrate	N.D	N.D	N.D	21.41	14.03	N.D	N.D	N.D	7.03	<LOQ
Bezafibrate	12.88	19.15	28.40	17.11	<LOQ	24.15	11.70	19.03	16.04	33.58
Lipid regulator drugs										
Gemfibrozil	8.15	5.39	6.01	4.81	5.07	N.D	N.D	N.D	4.78	2.91
Diuretics										
Furosemide	N.D	<LOQ	<LOQ	9.63	6.91	<LOQ	21.06	40.11	157.89	12.54
Hydrochlorothiazide	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	N.D	N.D	N.D	<LOQ	N.D
Sediment samples	**KL_{S1}**	**KL_{S2}**	**KL_{S3}**	**KL_{S4}**	**KL_{S5}**	**KL_{S6}**	**KL_{S7}**	**KL_{S8}**	**KL_{S9}**	**KL_{S10}**
Anti-diabetics										
Glibenclamide	N.D	N.D	N.D	N.D	N.D	6.22	8.91	6.21	<LOQ	<LOQ
Psychiatric drugs										
Diazepam	4.51	3.10	4.61	9.36	<LOQ	<LOQ	<LOQ	4.26	10.11	2.21
Lorazepam	N.D	N.D	N.D	N.D	N.D	N.D	<LOQ	<LOQ	<LOQ	<LOQ
Antibiotics										
Azithromycin	N.D	N.D	N.D	N.D	5.41	N.D	N.D	N.D	4.66	2.03
Chloramphenicol	22.07	17.33	10.74	5.73	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	4.91
Clarithromycin	<LOQ	<LOQ	<LOQ	N.D	N.D	6.44	8.91	8.41	9.31	<LOQ

Table 1 (continued)

PhACs	Sampled point									
Water samples	KL_{W1}	KL_{W2}	KL_{W3}	KL_{W4}	KL_{W5}	KL_{W6}	KL_{W7}	KL_{W8}	KL_{W9}	KL_{W10}
Erythromycin	N.D	N.D	N.D	N.D	<LOQ	<LOQ	<LOQ	20.44	6.83	<LOQ
Josamycin	N.D	N.D	N.D	N.D	N.D	<LOQ	5.92	3.04	N.D	N.D
Metronidazole	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Tylosine A	<LOQ	5.83	5.88	3.06	8.06	<LOQ	N.D	N.D	3.66	<LOQ
Trimethoprim	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Analgesics & anti-inflammatory										
Acetaminophen	105.11	39.66	40.21	26.81	70.99	15.06	5.14	N.D	10.31	41.99
Butalbital	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Carbamazepine	N.D	N.D	N.D	N.D	N.D	<LOQ	<LOQ	2.58	8.94	3.91
Diclofenac	N.D	N.D	N.D	N.D	<LOQ	<LOQ	<LOQ	20.44	6.83	<LOQ
Ibuprofen	10.31	33.04	19.52	21.03	14.42	N.D	<LOQ	<LOQ	69.21	5.01
Indomethacin	<LOQ	4.09	<LOQ	<LOQ	N.D	<LOQ	N.D	N.D	11.01	N.D
Ketoprofen	14.31	4.22	<LOQ	<LOQ	N.D	N.D	N.D	N.D	N.D	N.D
Mefenamic acid	6.91	4.06	4.11	<LOQ	<LOQ	<LOQ	<LOQ	N.D	<LOQ	<LOQ
Naproxen	N.D	6.11	N.D	<LOQ	<LOQ	N.D	N.D	N.D	N.D	N.D
Phenazone	<LOQ	4.88	<LOQ	<LOQ	N.D	N.D	N.D	N.D	<LOQ	<LOQ
Tramadol	2.66	2.91	<LOQ	5.99	3.41	13.77	10.25	56.82	<LOQ	<LOQ
β-blockers										
Atenolol	N.D	N.D	N.D	N.D	N.D	N.D	4.11	4.78	3.90	<LOQ
Nadolol	N.D	N.D	N.D	N.D	3.22	N.D	N.D	N.D	<LOQ	5.33
Anti-ulcer agents										
Cimetidine	N.D	N.D	N.D	N.D	<LOQ	<LOQ	N.D	N.D	<LOQ	<LOQ
Famotidine	N.D	N.D	N.D	N.D	<LOQ	<LOQ	N.D	N.D	N.D	N.D
Ranitidine	20.11	5.26	3.33	4.11	N.D	N.D	N.D	N.D	N.D	<LOQ
Cholesterol-lowering statin										
Atorvastatin	16.48	4.46	3.61	N.D	N.D	N.D	8.04	4.99	6.11	7.07
Mevastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Pravastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Fenofibrate	N.D	<LOQ	<LOQ	<LOQ	<LOQ	N.D	N.D	N.D	4.91	N.D
Bezafibrate	21.73	18.31	3.84	<LOQ	<LOQ	35.17	<LOQ	<LOQ	<LOQ	N.D
Lipid regulator drugs										
Gemfibrozil	2.51	2.44	1.58	2.44	7.99	N.D	N.D	N.D	<LOQ	<LOQ
Diuretics										
Furosemide	N.D	N.D	N.D	4.88	2.16	<LOQ	<LOQ	<LOQ	N.D	N.D
Hydrochlorothiazide	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

<LOQ denotes values less than the limit of quantitation

N.D denotes non-detected

LOQ limit of quantitation

mevastatin, hydrochlorothiazide, and butalbital was observed in all sediment samples.

Samples collected from sites KL1 and KL9 showed the highest average concentrations of PhACs in both sample types, which may be attributed to two main reasons. Sampled site KL1 is close to Agbogbloshie dumping sites, and consequently, high aqueous concentrations of PhACs can be detected due to the influence of sewage discharges. Also, sampled site KL9 is the main downstream, which serves as a retention tank (i.e., the inlet of water) to the coast of the Gulf of Guinea. A decrease in the inflow velocity of water from the lagoon to the coast may occur at site KL9. As a result, the moving water may deposit larger and heavier suspended materials within the vicinity of sampled site KL9. In comparison, smaller and lighter suspended materials settled on the coast of the Gulf of Guinea (i.e., sampled site KL10). According to Farkas et al. (2007), with the decrease in flow velocity in the retention tank, the larger and heavier fractions of suspended solids are deposited near the inlet. In contrast, the smaller and lighter fraction settled towards the outlet. During sediment samples preparation for extraction and analysis, there is an observation of many larger and heavier fresh organic materials deposited in sediment collected from sampled site KL9 compared to other sediment samples from other sampled sites except for sediment sample from sampled site KL1. Kummerer (2004)

reported that most of PhACs are organic-loving. Therefore, when PhACs enter the aquatic environment, they may likely form associations with organic materials more than inorganic materials. That may be the reason why KL9 exhibited the highest average concentrations of PhACs in both sample types.

Table 2 depicts the raw toxicological data obtained from the open literature (Sanderson et al., (2003) [EU and

Table 2 Raw toxicological data for the 35 detected pharmaceutically active compounds (PhACs)

PhACs	Eco-toxicological data							AF
	Based on the acute test result			Based on the chronic test result			Based on SSD	
	$E(L)C_{50}$ (Fish) [ng/L]	$E(L)C_{50}$ (Daphnid)	$E(L)C_{50}$ (Algae)	NOEC (Fish)	NOEC (Daphnid)	NOEC (Algae)	HC5	
Anti-diabetics								
Glibenclamide	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Psychiatric drugs								
Diazepam	2.8E+07	2E+06	5.5E+06	N.D	N.D	N.D	N.D	1.00E+03
Lorazepam	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Antibiotics								
Azithromycin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Chloramphenicol	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Clarithromycin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Erythromycin	5E+06	7.8E+06	4.3E+06	N.D	N.D	N.D	N.D	1.00E+03
Josamycin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Metronidazole	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Tylosine A	2.74E+07	6.6E+07	1.6E+07	N.D	N.D	N.D	N.D	1.00E+03
Trimethoprim	7.95E+08	4.8E+06	2.6E+06	N.D	N.D	N.D	N.D	1.00E+03
Analgesics & anti-inflammatory								
Acetaminophen	2.58E+08	4.1E+07	2.559E+09	N.D	N.D	N.D	N.D	1.00E+03
Butalbital	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Carbamazepine	1.01E+08	1.11E+08	7E+07	N.D	N.D	N.D	N.D	1.00E+03
Diclofenac	5.32E+08	5.057E+09	2.911E+09	N.D	N.D	N.D	N.D	1.00E+03
Ibuprofen	5E+06	3.8E+07	2.6E+07	N.D	N.D	N.D	N.D	1.00E+03
Indomethacin	3.9E+06	2.6E+07	1.8E+07	N.D	N.D	N.D	N.D	1.00E+03
Ketoprofen	3.2E+07	2.48E+08	1.64E+08	N.D	N.D	N.D	N.D	1.00E+03
Mefenamic acid	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Naproxen	3.4E+07	1.5E+07	2.2E+07	N.D	N.D	N.D	N.D	1.00E+03
Phenazone	3E+06	6.7E+06	1.1E+06	N.D	N.D	N.D	N.D	1.00E+03
Tramadol	7.72E+08	3.20E+04	1.04E+06	N.D	N.D	N.D	N.D	1.00E+03
β-blockers								
Atenolol	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Nadolol	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Anti-ulcer agents								
Cimetidine	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Famotidine	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Ranitidine	1.076E+09	6.3E+07	6.6E+07	N.D	N.D	N.D	N.D	1.00E+03
Cholesterol-lowering statin								
Atorvastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Mevastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Pravastatin	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Fenofibrate	8E+05	3.5E+05	1.00E+05	N.D	N.D	N.D	N.D	1.00E+03
Bezifibrate	5.3E+06	2.5E+07	1.8E+07	N.D	N.D	N.D	N.D	1.00E+03
Lipid regulator drugs								
Gemfibrozil	9.00E+05	6E+06	4E+06	N.D	N.D	N.D	N.D	1.00E+03
Diuretics								
Furosemide	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Hydrochlorothiazide	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Eco-toxicological data were fetched from ECOSAR (Sanderson et al., (2003) EU, and US values)

N.D denotes non-detected

US]) for the 35 PhACs detected in the samples. The data helped calculate the PNEC values of each PhACs for fish, daphnids, and algae (Table 3). The toxicity data of sixteen out of the thirty-five PhACs detected in the samples were available in the experimental toxicological data. Therefore, the toxicity assessment of 16 PhACs was evaluated in this study.

Risk assessment evaluation

The RQ values obtained helped predict the environmental risk grade of each PhaACs on non-target organisms in the studied area. The results obtained from the calculated RQ for fish in water samples are shown in Table 4. The highest estimated RQ value obtained was ibuprofen in a water sample from sampled site KL_{W2} (2.1E−02). Low adverse risks indications to fish species were noticed for acetaminophen in a water sample from sampled site KL_{W9} (1.2E−02) and ibuprofen in water samples from sampled sites KL_{W1} (1.8E−02), KL_{W2} (1.1E−02), KL_{W4} (1.1E−02), and KL_{W9} (2.1E−02). No potential adverse impacts of acetaminophen and ibuprofen on fish species were observed based on the results obtained from other water samples. The other PhACs show negligible risks to fish species in all water samples collected from the studied area.

In regards to daphnids, the highest calculated RQ values obtained were for tramadol in samples collected from sampled stations KL_{W6} (32.9E−01), KL_{W7} (21.9E−01), and KL_{W8} (13.3E−01), suggesting a high ecological risk to daphnids in the studied area (Table 5). In addition, the estimated RQ values obtained for tramadol in samples collected from sampled sites KL_{W1} (1.6E−01), KL_{W2} (2.9E−01), KL_{W3} (1.9E−01), KL_{W4} (3.4E−01), KL_{W5} (2.7E−01), KL_{W9} (8.5E−01), and KL_{W10} (1.4E−01) indicate medium risk to daphnids. However, acetaminophen exhibited low risks to daphnids at sampled sites KL_{W1} (6.4E−02) and KL_{W9} (7.3E−02). For fenofibrate, there is an observation of low risks to daphnids at sampled sites KL_{W4} (6.1E−02), KL_{W5} (4.0E−02), and KL_{W9} (2.0E−02). The other PhACs posed negligible risks to daphnids in all samples.

The highest computed RQ values recorded for algae were for fenofibrate at sampled sites KL_{W5} (21.0E−01) and KL_{W5} (14.0E−01), indicating high ecological risk. Also, the RQ value recorded for fenofibrate in a sample collected from sampled site KL_{W9} (7.0E−01) suggests medium risk to algae (Table 6). At sampled station KL_{W6}, the calculated RQ value for tramadol (1.1E−02) indicates a low risk to algae. Based on the computed RQ results obtained, the other PhACs present negligible risks to algae. The calculated toxic unit (TU) value for each sample at each sampled site indicates that non-target organisms in the Korle Lagoon are under medium risk of threat due to the accumulation of PhACs in the water (See Tables 4, 5, and 6).

Table 3 Calculated PNEC for non-target organisms (Fish, Daphnid, and Algae)

PhACs	PNEC [ng/L]		
	Fish	Daphnid	Algae
Anti-diabetics			
Glibenclamide	9.00E+02	6.00E+03	4.0E+03
Psychiatric drugs			
Diazepam	2.8E+04	2.00E+03	5.5E+03
Lorazepam	–	–	–
Antibiotics			
Azithromycin	–	–	–
Chloramphenicol	–	–	–
Clarithromycin	–	–	–
Erythromycin	5.00E+03	7.8E+03	4.3E+03
Josamycin	–	–	–
Metronidazole	–	–	–
Tylosine A	2.74E+04	6.5E+04	1.6E+04
Trimethoprim	7.95E+05	4.8E+03	2.6E+03
Analgesics & anti-inflammatory			
Acetaminophen	2.58E+05	4.1E+04	2.559E+06
Butalbital	–	–	–
Carbamazepine	1.01E+05	1.11E+05	7.00E+04
Diclofenac	5.32E+05	5.057E+06	2.911E+06
Ibuprofen	5.00E+03	3.8E+04	2.6E+04
Indomethacin	3.9E+03	2.6E+04	1.8E+04
Ketoprofen	3.2E+04	2.48E+05	1.64E+05
Mefenamic acid	–	–	–
Naproxen	3.4E+04	1.5E+04	2.2E+04
Phenazone	3.0E+03	6.7E+03	1.1E+03
Tramadol	7.72E+05	3.2E+01	1.04E+03
β-blockers			
Atenolol	–	–	–
Nadolol	–	–	–
Anti-ulcer agents			
Cimetidine	–	–	–
Famotidine	–	–	–
Ranitidine	1.07E+06	6.3E+04	6.6E+04
Cholesterol-lowering statin			
Atorvastatin	–	–	–
Mevastatin	–	–	–
Pravastatin	–	–	–
Fenofibrate	8.00E+02	3.5E+02	1.00E+02
Bezifibrate	5.3E+03	2.5E+04	1.8E+04
Lipid regulator drugs			
Gemfibrozil	9.00E+02	6.00E+03	4.0E+03
Diuretics			
Furosemide	–	–	–
Hydrochlorothiazide	–	–	–

Discussion

Algae serve as a primary producer in the food chain process (algae ← daphnid ← fish). Therefore, any threat of algae's habitat due to PhACs accumulation can reduce its growth, development, production, and population. On the other

Table 4 Calculated RQ and TU values for fish in the Korle Lagoon ecosystem

PhACs	Korle Lagoon (KL1 – KL10)									
	KL_{W1} RQ	KL_{W2}	KL_{W3}	KL_{W4}	KL_{W5}	KL_{W6}	KL_{W7}	KL_{W8}	KL_{W9}	KL_{W10}
Anti-diabetics										
Glibenclamide	–	–	–	–	–	–	–	–	–	–
Psychiatric drugs										
Diazepam	3.9E−04	3.4E−04	5.8E−04	2.1E−04	2.0E−04	6.7E−04	6.8E−04	3.9E−04	6.8E−04	2.2E−04
Lorazepam	–	–	–	–	–	–	–	–	–	–
Antibiotics										
Azithromycin	–	–	–	–	–	–	–	–	–	–
Chloramphenicol	–	–	–	–	–	–	–	–	–	–
Clarithromycin	–	–	–	–	–	–	–	–	–	–
Erythromycin	–	–	–	–	–	–	–	–	1.0E−03	–
Josamycin	–	–	–	–	–	–	–	–	–	–
Metronidazole	–	–	–	–	–	–	–	–	–	–
Tyrosine A	2.2E−04	2.2E−04	1.1E−04	3.0E−04	–	–	–	–	1.4E−04	–
Trimethoprim	–	–	–	–	–	–	–	–	–	–
Analgesics & anti-inflammatory										
Acetaminophen	1.0E−02	3.8E−04	2.4E−04	7.3E−04	6.7E−04	1.6E−04	–	–	1.2E−02	–
Butalbital	–	–	–	–	–	–	–	–	–	–
Carbamazepine	–	–	–	–	–	6.8E−05	1.0E−04	8.2E−04	6.4E−05	–
Diclofenac	3.9E−04	3.4E−04	5.8E−04	2.1E−04	2.0E−04	6.7E−04	6.8E−04	3.9E−04	6.8E−04	2.2E−04
Ibuprofen	1.8E−02	1.1E−02	6.4E−03	1.1E−02	5.6E−03	–	2.4E−03	1.9E−03	2.1E−02	1.8E−03
Indomethacin	2.8E−03	1.6E−03	1.5E−03	–	1.2E−03	–	–	–	1.2E−03	–
Ketoprofen	8.1E−04	4.3E−04	1.9E−04	2.5E−04	–	–	–	–	–	–
Mefenamic acid	–	–	–	–	–	–	–	–	–	–
Naproxen	–	2.4E−04	–	–	9.3E−05	–	–	–	6.1E−05	–
Phenazone	2.1E−03	3.9E−03	1.4E−03	–	–	–	–	–	1.1E−03	–
Tramadol	6.5E−06	1.2E−05	7.7E−06	1.4E−05	1.1E−05	1.4E−04	9.1E−05	5.5E−05	3.5E−05	6.0E−06
β-blockers										
Atenolol	–	–	–	–	–	–	–	–	–	–
Nadolol	–	–	–	–	–	–	–	–	–	–
Anti-ulcer agents										
Cimetidine	–	–	–	–	–	–	–	–	–	–
Famotidine	–	–	–	–	–	–	–	–	–	–
Ranitidine	2.1E−05	4.3E−05	8.7E−06	9.6E−06	–	–	–	–	–	–
Cholesterol-lowering statin										
Atorvastatin	–	–	–	–	–	–	–	–	–	–
Mevastatin	–	–	–	–	–	–	–	–	–	–
Pravastatin	–	–	–	–	–	–	–	–	–	–
Fenofibrate	–	–	–	–	–	–	–	–	8.8E−03	–
Bezafibrate	2.4E−03	3.6E−03	5.4E−03	3.2E−03	–	4.6E−03	2.2E−03	3.6E−03	3.0E−03	6.3E−03
Lipid regulator drugs										
Gemfibrozil	9.1E−03	6.0E−03	6.7E−03	5.3E−03	5.6E−03	–	–	–	5.3E−03	3.2E−03
Diuretics										
Furosemide	–	–	–	–	–	–	–	–	–	–
Hydrochlorothiazide	–	–	–	–	–	–	–	–	–	–
Toxic unit (TU)	4.6E−02	2.8E−02	2.2E−02	2.1E−02	1.4E−02	5.0E−03	5.5E−03	6.2E−03	5.4E−02	1.2E−02

hand, daphnids and fingerlings (young fishes) depend primarily on phytoplanktons such as algae for nourishment. Thus, any risk of phytoplankton's habitat due to PhACs accumulation is indirectly a threat to daphnids and fingerlings. Fish species depend on the secondary producers (i.e., daphnids) in the aquatic ecosystem for food. Therefore, an ecological threat due to PhACs accumulation to secondary producers (daphnids) negatively affects the consumer's growth, development, and yield (fish). This situation is a public health concern because human also depends on fish species for food. Thus, any imbalances in the aquatic ecology due to the accumulation of PhACs may reduce fish

Table 5 Calculated RQ and TU values for daphnid in the Korle Lagoon ecosystem

PhACs	Korle Lagoon (KL1 – KL10)									
	KL_{W1} RQ	KL_{W2}	KL_{W3}	KL_{W4}	KL_{W5}	KL_{W6}	KL_{W7}	KL_{W8}	KL_{W9}	KL_{W10}
Anti-diabetics										
Glibenclamide	–	–	–	–	–	–	–	–	–	–
Psychiatric drugs										
Diazepam	5.5E−03	4.7E−03	8.1E−03	2.9E−03	2.9E−03	9.4E−03	9.5E−03	5.4E−03	9.5E−03	3.0E−03
Lorazepam	–	–	–	–	–	–	–	–	–	–
Antibiotics										
Azithromycin	–	–	–	–	–	–	–	–	–	–
Chloramphenicol	–	–	–	–	–	–	–	–	–	–
Clarithromycin	–	–	–	–	–	–	–	–	–	–
Erythromycin	–	–	–	–	–	–	–	–	6.6E−04	–
Josamycin	–	–	–	–	–	–	–	–	–	–
Metronidazole	–	–	–	–	–	–	–	–	–	–
Tyrosine A	–	–	–	–	6.3E−05	4.7E−05	–	–	–	–
Trimethoprim	–	–	–	–	–	–	–	–	–	–
Analgesics & anti-inflammatory										
Acetaminophen	6.4E−02	2.4E−03	1.5E−03	4.6E−03	4.2E−03	1.0E−03	–	–	7.3E−02	–
Butalbital	–	–	–	–	–	–	–	–	–	–
Carbamazepine	–	–	–	–	–	6.1E−05	8.9E−05	7.3E−05	5.7E−05	–
Diclofenac	–	–	–	–	–	–	–	2.0E−05	8.7E−06	8.9E−07
Ibuprofen	2.3E−03	1.5E−03	8.4E−04	1.5E−03	7.3E−04	–	3.2E−04	2.5E−04	2.8E−03	2.4E−04
Indomethacin	4.2E−04	2.3E−04	1.5E−04	–	1.8E−04	–	–	–	1.5E−04	–
Ketoprofen	9.3E−05	4.9E−05	2.2E−05	2.9E−05	–	–	–	–	–	–
Mefenamic acid	–	–	–	–	–	–	–	–	–	–
Naproxen	–	5.4E−04	–	–	2.1E−04	–	–	–	1.4E−04	–
Phenazone	9.2E−04	2.2E−03	6.1E−04	–	–	–	–	–	5.0E−04	–
Tramadol	1.6E−01	2.9E−01	1.9E−01	3.4E−01	2.7E−01	32.9E−01	21.9E−01	13.3E−01	8.5E−01	1.4E−01
β-blockers										
Atenolol	–	–	–	–	–	–	–	–	–	–
Nadolol	–	–	–	–	–	–	–	–	–	–
Anti-ulcer agents										
Cimetidine	–	–	–	–	–	–	–	–	–	–
Famotidine	–	–	–	–	–	–	–	–	–	–
Ranitidine	3.6E−04	2.6E−04	1.5E−04	1.6E−04	–	–	–	–	–	–
Cholesterol-lowering statin										
Atorvastatin	–	–	–	–	–	–	–	–	–	–
Mevastatin	–	–	–	–	–	–	–	–	–	–
Pravastatin	–	–	–	–	–	–	–	–	–	–
Fenofibrate	–	–	–	6.1E−02	4.0E−02	–	–	–	2.0E−02	–
Bezafibrate	5.2E− 04	7.7E−04	1.1E−03	6.8E−04	–	9.7E−04	4.7E−04	7.6E−04	6.4E−04	1.3E−04
Lipid regulator drugs										
Gemfibrozil	1.4E−03	9.0E−04	1.0E−03	8.0E−04	8.5E−04	–	–	–	8.0E−04	4.8E−04
Diuretics										
Furosemide	–	–	–	–	–	–	–	–	–	–
Hydrochlorothiazide	–	–	–	–	–	–	–	–	–	–
Toxic unit (TU)	2.4E−01	3.0E−01	2.0E−01	4.1E−01	3.2E−01	33.0 E−01	22.0E−01	13.4E−01	9.6E−01	1.6E−01

production and yield. The bioaccumulation of these drugs in fish species may interact with the chemicals and the molecular structures within the fish to cause changes in sex sequence, DNA alternation, and other molecular and chemical changes that may be detrimental to the fish, fishes, and humans. The accumulation of PhACs in fishes may also cause changes in nutritional quality.

Conclusions

This work evaluates the concentrations of PhACs in water and sediments of the Korle Lagoon and their risks to fish, daphnid, and algae. It is observed that LC-MS/MS is a feasible analytical technique for the investigation of PhACs concentrations in water and surface sediment samples. The highest average

Table 6 Calculated RQ and TU values for algae in the Korle Lagoon ecosystem

PhACs	Korle Lagoon (KL1 – KL10)									
	KL_{W1} RQ	KL_{W2}	KL_{W3}	KL_{W4}	KL_{W5}	KL_{W6}	KL_{W7}	KL_{W8}	KL_{W9}	KL_{W10}
Anti-diabetics										
Glibenclamide	–	–	–	–	–	–	–	–	–	–
Psychiatric drugs										
Diazepam	2.0E−03	1.7E−03	2.9E−03	1.0E−03	1.0E−03	3.4E−03	3.5E−03	2.0E−03	3.5E−03	1.1E−03
Lorazepam	–	–	–	–	–	–	–	–	–	–
Antibiotics										
Azithromycin	–	–	–	–	–	–	–	–	–	–
Chloramphenicol	–	–	–	–	–	–	–	–	–	–
Clarithromycin	–	–	–	–	–	–	–	–	–	–
Erythromycin	–	–	–	–	–	–	–	–	1.2E−03	–
Josamycin	–	–	–	–	–	–	–	–	–	–
Metronidazole	–	–	–	–	–	–	–	–	–	–
Tyrosine A	–	–	–	–	2.6E−04	1.9E−04	–	–	–	–
Trimethoprim	–	–	–	–	–	–	–	–	–	–
Analgesics & anti-inflammatory										
Acetaminophen	1.0E−03	3.8E−05	2.4E−05	7.4E−05	6.8E−05	1.8E−05	–	–	1.2E−03	–
Butalbital	–	–	–	–	–	–	–	–	–	–
Carbamazepine	–	–	–	–	–	9.9E−05	1.4E−4	1.2E−04	9.2E−05	–
Diclofenac	–	–	–	–	–	–	–	3.5E−05	1.5E−05	1.6E−06
Ibuprofen	3.4E−03	2.2E−03	1.2E−03	2.1E−03	1.1E−03	–	4.7E−04	3.6E−04	4.1E−03	3.5E−04
Indomethacin	6.1E−04	3.4E−04	3.2E−04	–	2.6E−04	–	–	–	–	–
Ketoprofen	1.6E−04	8.4E−05	3.7E−05	4.9E−05	–	–	–	–	–	–
Mefenamic acid	–	–	–	–	–	–	–	–	–	–
Naproxen	–	3.6E−04	–	–	1.4E−04	–	–	–	9.4E−05	–
Phenazone	5.6E−03	1.1E−02	3.7E−03	–	–	–	–	–	3.1E−03	–
Tramadol	4.8E−04	8.8E−04	5.7E−04	1.1E−03	8.5E−04	1.1E−02	7.0E−03	4.3E−03	2.7E−03	4.6E−04
β-blockers										
Atenolol	–	–	–	–	–	–	–	–	–	–
Nadolol	–	–	–	–	–	–	–	–	–	–
Anti-ulcer agents										
Cimetidine	–	–	–	–	–	–	–	–	–	–
Famotidine	–	–	–	–	–	–	–	–	–	–
Ranitidine	3.5E−04	2.4E−04	1.4E−04	1.6E−04	–	–	–	–	–	–
Cholesterol-lowering statin										
Atorvastatin	–	–	–	–	–	–	–	–	–	–
Mevastatin	–	–	–	–	–	–	–	–	–	–
Pravastatin	–	–	–	–	–	–	–	–	–	–
Fenofibrate	–	–	–	21.4E−01	14.0E−01	–	–	–	7.0E−01	–
Bezifibrate	7.2E−04	1.1E−03	1.6E−03	1.0E−03	1.3E−03	6.5E−04	1.1E−03	–	8.9E−04	1.9E−03
Lipid regulator drugs										
Gemfibrozil	2.0E−03	1.4E−03	1.5E−03	1.2E−03	1.3E−03	–	–	–	1.2E−03	7.3E−04
Diuretics										
Furosemide	–	–	–	–	–	–	–	–	–	–
Hydrochlorothiazide	–	–	–	–	–	–	–	–	–	–
Toxic unit (TU)	1.6E−02	1.9E−02	1.2E−02	21.5E−01	14.1E−01	1.5E−02	1.2E−02	7.9E−03	7.2E−01	4.5E−03

concentrations and frequency of PhACs detected were analgesics/anti-inflammatory drugs such as acetaminophen and ibuprofen. In general, the results of toxic unit (TU) obtained in each sample at each sampled site indicate that non-target organisms in the studied area are under medium risk of threat due to the accumulation of PhACs in the water. The distribution of PhACs between water and suspended solids/sediments is a crucial issue because some of PhACs are ideally bound to the solid phase. Thus, further studies should not limit to the water phase and sediments but also suspended solids. It is further recommended that ongoing water quality monitoring and repeated toxicological testing for PhACs be encouraged to understand the actual risk associated with PhACs contaminants in various aquatic bodies.

Data availability

All data generated or analyzed during this study are included in this paper.

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Author contributions The author is responsible for ensuring that the descriptions are accurate. Author contributed in multiple roles: Conceptualization, Methodology, Formal Analysis, Investigation, etc.

Compliance with ethical standards

Conflict of interest The author declares no competing interests.

Ethical approval and consent to participate The study was carried out in the University of Ghana, Legon—Accra, Department of Chemistry Laboratories. All samples were obtained after written informed consent with University of Ghana Research Ethics Board approval of the study in accordance with the Declaration of Ghana Environmental Protection Agency (Ghana EPA) and Food & Drugs Authority (GFDA) laws. The study was established following the approval of the University of Ghana Research Ethics Committee, number of UGDC/71105/2021-99.

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