

SEASONAL OCCURRENCE OF IBUPROFEN IN SEDIMENT, WATER, AND BIOTA IN RIVER OWENA AND OGBESE, AND ITS ECOLOGICAL RISK ASSESSMENT

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Abstract

The volume of pharmaceuticals discharged into the environment increases daily as a consequence of human life. In the present study, the seasonal variation of ibuprofen in sediment, biota, water, and their exposure risk were investigated in River Owena and Ogbese, Nigeria. The high-performance liquid chromatography coupled to a mass spectrometer (HPLC-MS/MS) was used to analyze the samples after clean up and pre-concentration by solid-phase extraction. The mean concentration of IBU in the samples spanned a range of 1.75 - 2.75 µg/g in sediment, 0.01 - 15.00 µg/g in fish, and 0.00002 - 0.005 µg/ml in water. The measurement of IBU in the sediment and water was significantly elevated in the dry season than the wet season, whereas the opposite was the case in biota. There was a significant interaction between season, media, and rivers with respect to IBU occurrence in the sampled rivers. The calculated bio-water accumulation factor (BWAf) was as high as 750,000 µg/g in fish, proving IBU is extremely bio-accumulative. The ecotoxicological risk assessment for average and worst possible outcome showed that the risk quotient (RQ) for IBU present in the water was sufficient to cause toxicity to fish in both freshwater bodies. The potential bioavailability of IBU to aquatic fauna for prolonged periods spanning several months can result in its circling back into the food web afterward. The baseline info provided by this study in these freshwaters may provide valuable information for the implementation of safety limits for the management of IBU influx into the environment.

Keywords: Ibuprofen, Owena, Ogbese, Bioaccumulation, Water, Sediment, Biota, and risk assessment.

1.0 Introduction

There has been a surge in the volume of legacy and emerging contaminants in the environment, such as pharmaceutical compounds utilized as prophylaxis, diagnosis, and treatment of diseases. As a result, the pharmaceutical industry is amongst the fastest developing sector globally (Mompelat *et al.*, 2009). A considerable rise in the consumption of non-prescribed has been detected, a prominent category consist of the non-steroid anti-inflammatory drugs (NSAIDs), utilized in the remedy of pain, inflammation, and arthritic conditions (Sonowska *et al.*, 2009). NSAIDs function via the suppression of the cyclooxygenase (COX) enzymes known to incite the biosynthesis of prostaglandins and thromboxane from arachidonic acid (Modi *et al.*, 2012; Lucia *et al.*, 2015).

Scientific research over the past two decades has shown that NSAIDs, like all pharmaceuticals, are ubiquitous in the environment, primarily via excretion in its parent form and metabolites through faeces or urine (Metcalfe *et al.*, 2003; Kummerer, 2010), unabating wastewater discharges from drug factories, hospitals, agribusiness and fisheries, clustered homes and areas with people. The significant source of pharmaceuticals in wastewater, underground, and surface waters can also arise from the inappropriate disposal of unused and expired drugs, and terminal effluent wastewater (Sandor *et al.*, 2012). Due to the molecular and physicochemical properties of NSAIDs, these drugs can persist in the aqueous environment (Akbar *et al.*, 2015). Of all detected pharmaceuticals, the NSAID ibuprofen (IBU) was consistently detected at higher concentrations than other drugs in the effluents of wastewater treatment plants (WWTPs) (Lishman *et al.*, 2006).

IBU (RS -2-[4-(2-methyl propyl)phenyl] propanoic acid), a non-selective NSAID, has a global annual production rate of several kilotons because it is among the most frequently prescribed and commonly used (Abraham and KI, 2005; Ali *et al.*, 2009). It is also enlisted as one of the core medicines in the World Health Organization (WHO) "Essential Drugs List" as a result of its widespread application as an anti-inflammatory, antipyretic, and analgesic compound (Han *et al.*, 2010). Due to its high rate of application in tandem with the drug pharmacokinetics (half-life, metabolism, faecal, and urinary excretion), IBU can build up to measurable levels in the ecosystem (Clevers, 2004).

IBU has been detected at varying concentrations in environmental samples, e.g., in wastewater from 37.99 µg/L in Nigeria (Lan *et al.*, 2019), to 45 µg/L in Canada (Guerra *et al.* 2014), 703–1673 µg/L in Pakistan, 221 µg/L in South Africa, and 5.78 µg/L in Belgium (Madikizela and Chimuka, 2016a; Ashfaq *et al.*, 2017a; Žur *et al.*, 2018). IBU has been detected in surface waters near releases from sewage effluents with a mean concentration of 0.02 – 79.45 µg/L (Nigeria), and

within a range of 0.0002- 5.04 µg/L in Brazil, Canada, China, Germany, Italy, Sweden, Britain and the United States of America (Olarinmoye *et al.*, 2016; Lan *et al.*, 2019). A review by Žur *et al.*, 2018, stated that IBU was recorded in receiving waters at a mean concentration range of 0.98 – 67 µg/L in Canada and Greece, 0.98 µg/L (Canada), 1.0 – 67 µg/L (Greece), < 15 – 414 µg/L (Korea), 5.0 – 280 µg/L (Taiwan), ND – 8.0 µg/L (France), and ND – 1417 µg/L (China) (Almeida *et al.*, 2013; Luo *et al.*, 2014).

According to Luo *et al.*, (2014), the mean concentration of IBU detected in groundwater in Europe was 3 ng/L, with a maximal concentration of 395 ng/L. In soil, detected IBU concentrations ranged between 321–610 µg/kg (Žur *et al.*, 2018; Ashfaq *et al.*, 2017a) to 0.213µg/L for soils irrigated with wastewater containing pharmaceutical residues (Žur *et al.*, 2018; Vazquez-Roig *et al.*, 2012). Pharmaceutical products are typically formulated to cross biological membranes, and thus the rate of uptake and internal concentrations are imperative. Therefore, to fully understand the potential for pharmaceuticals to induce harm in the aquatic ecosystem, it is crucial to assess the broader occurrence of the bioavailable fraction in biota (invertebrates, fish, plants, and algae). The choice of fish (due to its high rank in the aquatic food web) provides a broader understanding of the overall health of the environment since they are capable of integrating contaminants and pollutants from lower trophic levels. The popular NSAIDs, IBU, diclofenac, and naproxen have all been shown to accumulate in fish (Lahti *et al.*, 2011).

The potentially harmful impact of NSAIDs, together with their prevalent use and the potential for long-distance transport, makes it essential to monitor them in the various environmental matrice. In order to gain a proper insight into the transportation and fate of NSAIDs, the seasonal variation data of these compounds in various environmental media are essential. Recently, numerous studies have demonstrated the occurrence of pharmaceuticals in aquatic environments (Thomas *et al.*, 2018; Anekwe *et al.*, 2017). To the best of the authors' knowledge, none of such reports dwelled on the seasonal variation of IBU in various environmental matrices in sub-Saharan freshwaters in Africa has been published. Some of the published African reports focused more on wastewater and impacted surface water with pharmaceutical effluents, with little information on the bioaccumulation potential in biota and the environmental pollution caused by drugs on sediments and (Olarinmoye *et al.*, 2016., 2010; Madikizela *et al.*, 2017; Samuel *et al.*, 2018).

Therefore, this investigation seeks to evaluate the seasonal variation of IBU in sediment, biota, and water in two major freshwater bodies (River Owena and Ogbese) in Nigeria, and to evaluate the ecological risk factor it portends for the ecosystem.

2.0 Experimental

The Study Area

This investigation was conducted in River Ogbese (Figure 1: Longitudes 5°26'E to 6°34'E and latitudes 6°43'N to 7°17'N), and River Owena (Figure 2: longitudes 5°00'- 5°30'E and latitudes 7°00 - 7°30'N). These two freshwater bodies are prominent in southwest Nigeria, with a reasonable number of the populace dependent on them as a source of food (artisanal fisheries), drinking water, aquaculture business, irrigation, laundry, waste disposal and for industrial purposes on a large scale. The Owena river houses a dam, covering an appropriate surface area of 7.8 sq km and with the capacity to feed 60,000 m³/day to the water treatment plant built beside the dam.

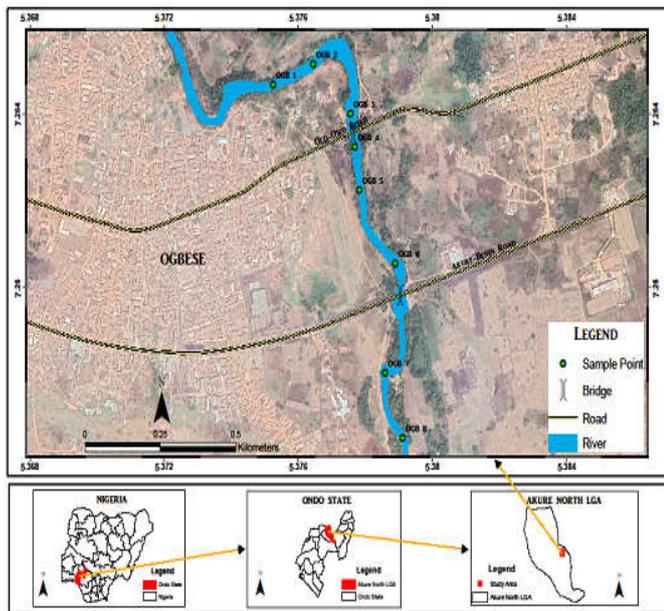


Figure 1: Showing River Ogbese Sampling Locations

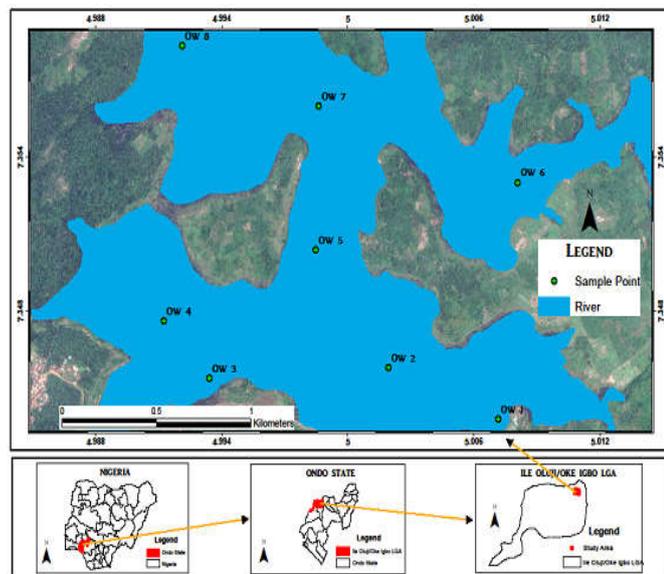


Figure 2: Showing River Owena Sampling Locations

Chemicals and materials

Analytical grade IBU, with a purity of 98 % or higher, was purchased from Bristol scientific, an authorized distributor of Sigma-Aldrich in Nigeria. Stock standard solutions of pharmaceuticals were prepared in methanol (HPLC grade, Merck) at 100 mg/L and were stored at -20 °C. Working standard solutions were daily prepared from the stock standard solution using methanol as solvent and kept at 4 °C before analysis. Amber glassware was used to prevent light degradation of pharmaceuticals.

All the solvents used, methanol, acetonitrile, Trifluoroacetic acid, and acetone, were of HPLC grade and were all purchased from the same source as IBU. Oasis HLB (6 mL, 200 g) was used to perform solid-phase extraction (SPE).

Collection of Samples, Processing, and Analysis

Between March 2018 and February 2019, composite sediment and water samples were collected in the morning from the designated sampling sites into 2 L amber coloured bottles and aluminum foil, respectively, ensuring that there was very minimal contamination of the sampling equipment and samples before, during, and after the sampling.

Water was sampled using the dip collection method, which involved decapping the bottles and dipping them below the surface (0 – 20 cm) at each sampling location until it was filled up to the shoulder to provide sufficient room for expansion during freezing. A few drops of concentrated hydrochloric acid (HCL) was added to adjust the pH of the sample to < 2, in order to decrease the activity of microbes, precipitation, and sorption losses to container walls (Ferhan and Ulan, 2017). For the sediment, Grab samples at a depth of 0 – 10 cm in all sampling sites were collected with the aid of depth samplers. Collected samples were allowed to drain and wrapped in aluminum foil. Following collection, water and sediment samples were placed in coolers with ice packs, transferred to the laboratory, and preserved at 4°C until further analysis. Live samples of two species of fish, *Clarias gariepinus* (Catfish) and *Tilapia zilli* (Tilapia spp) were obtained directly from fresh landings of fishers from the river bodies. All fish samples were wrapped in well-labeled aluminum foil (individual wrapping) and equally stored, transported, and preserved like the water and sediment sample for further analysis.

Sample pretreatment

Water

The frozen water sample was thawed and then sieved with cotton wool and Whatman filter paper dis 18 cm (0.45 µm) to eliminate particulates, samples were preserved in a frozen state before the solid phase extraction (SPE). Extraction was conducted using Oasis HLB cartridge (6 ml, 200 mg); cartridges were activated and conditioned with 6 mL methanol and 6 mL water, respectively. Precisely 500 mL of the sample was transferred into the cartridges and rinsed with 5% v/v methanol in water. Cartridges were eluted with 3 mL x 2 methanol and subsequently evaporated using nitrogen gas (N₂) and reconstituted with 0.5 mL of methanol before it was transferred to vials for HP-LC analysis using standards methods adopted from the USEPA (2011).

Sediment

Collected samples were air-dried at ambient temperature and away from plastic materials. 20 mL of Dichloromethane-Methanol (DCM) and methanol were used as extraction solvents for 2 g of the dry sample, and it was then sonicated for 30 mins at 50°C in an ultrasonic bath. The solvents were carefully decanted into a 100 mL beaker and evaporated to dryness using N₂. The sample was reconstituted with 2 mL methanol and makeup to 100 mL in a 100 mL volumetric flask. In the Solid-phase extraction (SPE), cartridges were primed and activated with 6 mL water and 6 mL methanol, respectively. 2 g of the sample was loaded into the cartridges and washed with 5% v/v methanol in water. Cartridges were eluted with 3 mL x 2 methanol and subsequently evaporated using N₂ and reconstituted with 0.5 mL of methanol before it was transferred to vials for HP-LC analysis using standards methods adopted from the USEPA (2011).

Biota

Tissues from sampled fish were collected and homogenized using a blender and stored in a freezer before extraction. The homogenized fish tissues were thawed, and a known weight in duplicate was combined with an extraction solvent (0.1M acetic / methanol) (2 g:10 mL). The duplicate samples were sonicated for 30 minutes, transferred to a centrifuge tube, and centrifuged at 4,000 rpm for 10 mins, and the supernatant was collected. The supernatants were pooled and evaporated using N₂ at 45°C and reconstituted with 0.5 mL of methanol and made up to 100 ml with water. In the SPE, cartridges were activated and conditioned with 6 mL methanol and 6mL water respectively. 100 mL of the sample was transferred into the cartridges and washed with 5% v/v methanol in water. Cartridges were eluted with 3 mL x 2 methanol and subsequently evaporated using N₂ and reconstituted with 0.5 mL of methanol before it was transferred to vials for HP-LC analysis using methods as described by Liu *et al.*, (2018) and Huerta *et al.*, (2013).

Analytical Procedure

The qualitative and quantitative analysis of IBU was conducted utilizing a high-performance liquid chromatography (HP-LC). Analytes were separated with the aid of an Agilent HPLC 1100 fitted a thermostated column compartment, an auto liquid sampler, a binary pump, a multi-wavelength detector, and a degasser. Samples were analyzed under LC-tandem MS conditions based on the detailed description of Gentili *et al.*, 2012. In brief, the IBU was separated through a reversed-phase ion-pair chromatography on an XTerra-MS C18 (150 × 4.6 mm I.D.; 5 µm) (Waters, Milano, Italy), using a mixture of acetonitrile: methanol (50:50, v/v) as eluent A and water as eluent B; dibutyl amine (0.2 mM) was added to both phases as an ion-pair agent.

Risk Assessment

The environmental risk associated with IBU was evaluated by calculating the risk quotient values (RQ) obtained by dividing the maximum measured environmental concentrations (MEC) by the corresponding predicted no-effect concentrations (PNEC) (Equation 1). PNEC values were estimated for *Vibrio fischeri* (bacteria), algae, *Daphnia magna*, and fish (*Clarias gariepinus*) from published acute toxicity data. Precisely, by dividing EC₅₀ values by an arbitrary safety

factor of 1000, PNEC was derived to capture the deduction from inter and intra-species sensitivity and variability (Hernando *et al.*, 2006; Sanderson *et al.*, 2004) (Equation 2).

$$RQ = \frac{MEC}{PNEC} \tag{Eqn. 1}$$

PNEC was calculated as:

$$PNEC = \frac{EC_{50} \text{ or } LC_{50}}{AF} \tag{Eqn. 2}$$

The values of EC₅₀ deployed in this investigation were retrieved from the literature and are summarized in table 3. It is pertinent to state that when more than one EC₅₀ value was discovered, the lowest values were taken into consideration. The risk to biota was grouped into three categories: Low risk (RQ below 0.1), moderate risk (RQ 0.1 to below 1), and high risk (≥1) (de Souza *et al.*, 2009).

Statistical Analysis

The experimental data were analyzed using the SPSS statistical package (Version 25). Mean Concentrations of the compound detected in water, sediment, as well as biota samples in both rivers, were compared using a one-way analysis of variance (ANOVA) to separate the means. A generalized linear model (GLM) analysis was conducted to evaluate the interaction between media (sediment, water, and biota), season (wet and dry), and freshwater bodies (Owena and Ogbese). Significant differences were determined at *p* < 0.05.

3.0 Results and Discussion

Environmental Assessment of IBU in Water, Sediments, and Biota in River Owena and Ogbese, Ondo State

The seasonal concentration of IBU in sediment, water, and biota in river Ogbese and Owena are presented in table 1.

Sediment

In both freshwater bodies, the mean level of IBU was significantly higher (*p* < 0.05) in the dry season (1.89 - 2.74 µg/g), when compared to the wet season (1.75 - 2.52 µg/g). The highest mean concentration of IBU (2.74 µg/g) in the sediment was recorded in River Owena (dry), while the lowest mean level of 1.75 µg/g was recorded in River Ogbese (Wet). Sediments typically act as the ultimate sink for pollutants released into the environment (Malferrari *et al.*, 2009). The mean level of IBU in sediments seasonally varied in both rivers, with the dry season having a statistically high level than the wet season (Table 1). The seasonal variations of IBU in sediment were potentially influenced by limiting agents such as dissolved organic matter, pH, temperature, and salinity. In this study, the relatively high concentrations of IBU in the dry season could be attributed to an increase in salinity due to the “salting out” effect, acting in tandem to an acidified sediment, which greatly enhanced its sorption to sediment (Oh *et al.*, 2016). The high sediment concentration of IBU in both rivers may be ascribed to the high consumption rate of the drug either through prescription and over the counter purchases which eventually find their way into the environment via metabolic excretion or inappropriate disposal of unwanted and expired drugs (common in a developing economy like Nigeria).

Water

In water, the mean concentration of IBU in the dry season (0.003 – 0.005 µg/ml) in both rivers were significantly greater ($p < 0.05$) than levels detected in the wet season (0.00002 – 0.00003 µg/ml). The highest mean concentration of IBU (0.05 µg/ml) in the water was recorded in River Owena (dry), while the lowest mean level of 0.00002 µg/ml was recorded in River Owena (Wet). At low pH, weak acids like IBU with a pKa of 4.9 exist in a unionized form, which increases its hydrophobicity (William & Randy, 1997), and consequently increases its permeability to a biological membrane (Pranitha and Lakshmi, 2018). In this study, this pattern was corroborated entirely with a significantly high level of IBU in the dry season than wet season, and the corresponding significant high levels of IBU in biota in the wet season when compared to the dry season. An indication that the pH of the freshwater bodies in the wet season may be slightly acidic, likely influenced by climatic factors such as high precipitation of acidic rain, runoff via strongly acidic soils the study area is known for into the freshwaters (Fasina *et al.*, 2015). Fasina *et al.*, 2015, stated that soils of Ondo and Fagbo are significantly acidic (4.50) to moderately acidic (5.70), containing a lot of iron-manganese concretions, quartz stones, and gravels. The mean level of IBU in both fresh surface water bodies in this study was lower when compared to literature values from the basin of River Nairobi in Kenya (K'oreje *et al.*, 2012), and Umgeli River, South Africa (Solomon *et al.*, 2015). The significant variance in the concentration of IBU in both rivers could be a function of size, wet precipitation, topography, flow rate, and the proximity and volume of human activities.

Biota

In contrast to sediment and water, the mean level of IBU in biota in the wet season (0.44 - 15.00 µg/g) in both rivers was significantly higher ($p < 0.05$) than levels detected in the dry season (0.01 – 0.24 µg/g). The highest mean concentration of IBU (15.00 µg/g) in the biota was recorded in River Owena (wet), while the lowest mean level of 0.01 µg/g was recorded in River Ogbese (dry). The mean bio-water accumulation factor (BWAf) of IBU in biota in both rivers was severe in the wet season (14.666.67 – 750,000 µg/g) when compared to the dry season (3.33 – 48 µg/g). The highest BWAf was recorded river Owena (wet), closely followed by Ogbese (wet), > Owena (dry), and Ogbese (wet). Numerous invertebrates and non-target vertebrates share drug targets with humans (Gunnarsson *et al.*, 2008); thus, the high accumulation of IBU may induce the therapeutic effects of the drug in biota. The BWAf in both rivers showed IBU to be extremely bioaccumulative, having crossed the threshold limit of 5,000 for aquatic organisms (Arnot and Gobas, 2006). The measured BWAf in River Owena during the wet season was 7.8 times greater than the values reported by Lagesson *et al.*, 2016. They measured a BAF value of 96,000 for hydroxyzine in the *Planorbidae*, a freshwater snail that was exposed to a cocktail of pharmaceuticals in a semi-natural pond at Umea, Sweden. The extreme BWAf values could be as a consequence of the semi-persistent nature of the compound in the river bodies, the half-life of IBU in the environment is about 64 days which exceeds the United Nations Environmental Programme (UNEP) threshold limit at

60 days to define a chemical as persistent in the aquatic environment (Araujo *et al.*, 2014). The enormous bioaccumulation of IBU may also give rise to unexpected effects such as endocrine disruption, compulsive feeding, boldness, and aggression, not related to the desired therapeutic effects (Klimaszzyk and Rzymiski, 2019).

Table 1: Seasonal Assessment of IBU in Water, Sediments and Fish Tissue in River Owena and Ogbese, Nigeria

River	Season	Sediment	Water [µg/ml]	Biota [µg/g]	BWAf
		[µg/g]			[µg/g]
		M ± SE	M ± SE	M ± SE	
Owena	Wet	2.52 ± 0.03 ^f	0.00002 ± 0.11 ^d	15.00 ± 0.10 ^g	750,000
	Dry	2.74 ± 0.07 ^g	0.005 ± 0.06 ^e	0.24 ± 0.05 ^e	48
Ogbese	Wet	1.75 ± 0.01 ^d	0.00003 ± 0.17 ^d	0.44 ± 0.08 ^f	14,666.67
	Dry	1.89 ± 0.02 ^e	0.003 ± 0.02 ^e	0.01 ± 0.16 ^d	3.33

Note: Means values with the same superscript alphabets in the same column are not significantly different ($p < 0.05$) from each other

Interaction of Media (Sediment, water, and fish), Rivers (Owena and Ogbese) and Seasons (Wet and Dry), and their Influence on IBU of Concentration

A generalized linear model (GLM) analysis was conducted to examine the effect of medium (M), season (S), and river (R) on IBU concentration are presented in table 2. All effects were statistically relevant at the 0.05 level. There was a significant interaction between the effects of medium and season, $F(2, 60) = 8457.02$, $p = 0.000$, medium and river, $F(2, 60) = 7909.64$, $p = 0.000$; season and river, $F(1, 60), 9156.64$, $p = 0.000$, medium, season, and river, $F(2, 60) = 9300.36$, $p = 0.000$ on IBU concentration. The simple main effects analysis showed that the size of the river and season greatly influenced the dilution, solubility, and bioavailability of IBU to bioaccumulate in biota ($p = .000$).

The significant interaction ($p < 0.000$) between season, medium, and river concerning IBU detection in both water bodies can mainly be attributed to acidic soil type (Fasina *et al.*, 2015), and a high incidence and volume of acid rain. Ondo State is located along the Niger delta belt in Nigeria, a region that plays host to international oil exploration companies, with an attendant high natural gas flaring rate of 17.2 billion m³ per year as a by-product (Anslem, 2013). These flares emit a high volume of atmospheric contaminants such as oxides of Carbon, Sulphur, and Nitrogen (CO₂, SO₂, NO₂), which are precursors of acid rain. Thus, exposing the Niger delta area to regular incidences of acid rain with recorded pH ranging from 4.70 – 5.23 (Nduka *et al.*, 2013; Efe and Mogborukor, 2012).

Table 2: Interaction of Media (Sediment, water and fish), Rivers (Owena and Ogbese) and Seasons (Wet and Dry) and their Influence on IBU Concentration.

Source	df	MS	F	p	Effect Size
Medium	2	92.80	7437.09	.000	.995
Season	1	97.40	7806.07	.000	.992
River	1	134.76	10800.18	.000	.994
M x S	2	105.52	8457.02	.000	.997
M x R	2	98.69	7909.64	.000	.992
S x R	1	114.25	9156.64	.000	.991
S x M x R	2	116.05	9300.36	.000	.996
Error	60	2.18			
Corrected Total	35				

Note:— S= Season, R = River, M = Medium, MS = Mean squares

Table 3: Ecological Risk Assessment of IBU Using PNEC values Calculated from Ecotoxicological Studies Reported in The Literature and RQ Values for Water

Pharmaceutical compound	Species	EC ₅₀ (mg/L)	PNEC (µg/mL)	Reference	River	Risk quotients (RQ) for Water
IBP	Vibrio fischeri (bacteria)	37.5	0.038	(Camacho-Muñoz <i>et al.</i> 2010)	Owena	0.13
					Ogbese	0.08
	Algae	5.7	0.006	(Paíga <i>et al.</i> 2013)	Owena	0.83
					Ogbese	0.50
Daphnia magna	9.06	0.009	(Jones <i>et al.</i> 2002)	Owena	0.56	
				Ogbese	0.33	
Fish		0.38	0.0003	(Ogueji <i>et al.</i> 2017)	Owena	16.67
					Ogbese	10.00

Risk assessment

The risk quotient (RQ) values for ecological risk due to IBU in both rivers are presented in table 3. The RQs for freshwater organisms except for fish (10.00 – 16.67), were generally lower than 1 (0.08 – 0.83), implying no harm is expected to occur in these aquatic animals. The high RQ estimated for fish in both rivers suggest high acute/chronic toxicity risk to fish populations. The calculated RQ values for IBU did not seem to pose any risk for bacteria, algae, and daphnia magna, this was consistent with studies by Eslami *et al.*, 2015 and Pravin *et al.*, 2018, they reported that NSAIDs such as IBU, naproxen (NPX), diclofenac (DIC), and indomethacin (IDM) did not pose any risk to bacteria, algae, and daphnia magna. However, the high RQ values for IBU on fish in both rivers is an implication of the significant number of drug target orthologs in fish (Gunnarsson *et al.*, 2019). Gunnarsson *et al.*, (2019) reported that 90% of all human drug targets had orthologues in zebrafish (*D. rerio*), 64% of the targets had orthologues in the water flea (*D. pulex*), and 34% in the green algae (*Chlamydomonas reinhardtii*). A study by Nesbitt (2011) demonstrated that at a concentration of 100 ng/L, IBU and NPX induced a decrease in the rate of egg fertilization which can diminish spawning activities and fecundity, consequently leading to a decline in fish populations.

Conclusion

This study has confirmed the presence of IBU in sediment, biota, and water of freshwater bodies in Ondo State, Nigeria. The findings established that IBU is seemingly persistent in both sediment and water, with a high capacity to bioaccumulate in fish. The variation of the compound in various matrices established that season had a significant impact on its sorption, solubility, and bioavailability status. IBU in water posed a severe ecological risk to fish in both rivers, with RQ values as high as 16. The environmental concentration of IBU in these freshwater bodies represents a high risk to impact fish populations negatively. Due to the high likelihood of IBU to remain and greatly bioaccumulate in aquatic organisms, it is recommended that more comprehensive monitoring campaigns in freshwater bodies be implemented, especially in areas with high anthropogenic activities to prevent deterioration of aquatic life.

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Conflict of interest

There is no conflict of interest with this manuscript.

Authors Contribution

Conception: GAO

Design: GAO and JKS

Execution: GAO

Interpretation: GAO and JKS

Writing the paper: GAO

Proofreading the paper: JKS

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