Anthropic impacts on Sub-Saharan urban water resources through their pharmaceutical contamination (Yaoundé, Center Region, Cameroon)

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Title

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Title

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Abstract

Sub-Saharan urban centers have to tackle high population growth, lack of sanitation infrastructures and the need for good quality water resources. To characterize the impacts of anthropization on the water resources of the capital of Cameroon (Yaoundé), a multi-disciplinary approach was used in ten sub-watersheds (peri-urban and urban) of the Méfou watershed. Pharmaceutical residues were used as tracers of surface and groundwater contamination caused by the release of domestic wastewater from pit latrines and landfills. A water use survey was conducted in the vicinity of the sampling sites to better assess water use, treatment and management. Available land use and hydro-geomorphological data completed characterization of the sub-watersheds. The combined data showed that natural features (elevation, slope, and hydrography) and human activities (land use) favor rainfall-runoff events and hence surface water contamination. Pharmaceutical monitoring revealed contamination of both surface and groundwater especially in the urban sub-watersheds. Analgesics/anti-inflammatory drugs and anti-epileptic carbamazepine were the most frequently found compounds (in up to 91% of water samples) with concentrations of acetaminophen reaching 5,660 ng/L. In urban sub-watersheds, 50% of the groundwater sites used for drinking water were contaminated by diclofenac (476-518 ng/L), carbamazepine (263-335 ng/L), ibuprofen (141-276 ng/L), sulfamethoxazole (<2-1,285 ng/L) and acetaminophen (110-111 ng/L), emphasizing the need for a deeper understanding of the interactions between surface and groundwater. The use of groundwater as drinking water by 68% of the total population surveyed raises concerns about population exposure and potential health risks. This case study highlights the need for strategies to limit contamination of the water resource given the predicted future expansion of Sub-Saharan urban centers.

Key words

Pharmaceutical residues, water resources, water use, urbanization, wastewater, Sub-Saharan Africa

I. Introduction

Since the middle of the 19th century anthropization has had an impact on the aquatic environment and resources through land use modifications, environmental planning and the development of agriculture thereby altering the composition, functions and services provided by ecosystems (Guetté et al., 2018; Leduc et al., 2017; Misson et al., 2016). In highly anthropized areas like metropolises, increasing urbanization implies changes in water uses, an increase in water demand and degradation of water quality (Echart et al., 2012). Human activities in particular involve the release of anthropogenic contaminants into surface and groundwater resources (Archundia et al., 2017; Hayzoun et al., 2015; Mottes et al., 2015; Schaider et al., 2016).

Among anthropogenic contaminants, pharmaceutical residues have been the subject of numerous studies in recent decades all over the world (Beek et al., 2016; Carvalho and Santos, 2016; Gogoi et al., 2018; Madikizela et al., 2017). Improvement in analytical techniques has allowed their detection and quantification not only in waste water effluents but also in surface and groundwater including drinking water resources (Mompelat et al., 2009). Pharmaceutical residues are considered as anthropogenic tracers of the "urbanizing global water cycle" (Castiglioni et al., 2018).

Global pharmaceutical contamination of the aquatic environment has both specific and higher implications in developing countries particularly in sub-Saharan Africa. Both the increasing human pressure on water resources and the growing demand for freshwater in urban settlements lead to the risk of exposure of population and environmental exposure to a cocktail of urban contaminants including pharmaceutical residues (Gwenzi and Chaukura, 2018; Madikizela et al., 2017).

In sub-Saharan metropolises the main problem is the lack of disposal and treatment of wastewater and of solid and liquid waste. The lack and/or inadequate removal of pharmaceuticals during standard treatment of wastewater means raw or partially treated wastewater can be discharged into drinking water resources (Gwenzi and Chaukura, 2018). These risks have been poorly documented in sub-Saharan African and pioneer studies are currently being conducted to better understand the sources, occurrence and fate of pharmaceuticals in water bodies (Ebele et al., 2017; Madikizela et al., 2017). According to these reviews only pharmaceutical contamination of water bodies in South Africa, Kenya, Ghana, Mozambique and Nigeria have been partially monitored.

This aim of this study was thus to characterize the impact of anthropization on surface and groundwater using pharmaceuticals as tracers of urban contamination in a sub-Saharan capital city, Yaoundé, Center Region, Cameroon. With almost two million inhabitants and 6% demographic growth a year between 2000 and 2005 (BUCREP, 2010) Yaoundé faces heavy pressures on its water resources (Branchet et al., 2018; Djuikom et al., 2009; Menye et al., 2012;

Naah, 2013) and a crucial lack of sewage systems (Wethé et al., 2003). Waste management issues and the related occurrence of solid and liquid wastes in the urban streams were reported by previous literature (Lieunang Letche et al., 2009; Menye et al., 2012).

The main objective of this research is to provide baseline information on (i) the vulnerability of surface and groundwater resources by analyzing pharmaceutical contamination, (ii) population exposure to pharmaceuticals through their drinking water, and at the same time, (iii) to assess the suitability of pharmaceuticals as anthropic tracers in the specific context of the Méfou watershed.

Due to the scarcity of data concerning hydrology, land use, water use, waste management, and the consumption of pharmaceutical drugs by the inhabitants of Yaoundé, we used a multidisciplinary approach. Available land use and hydro geomorphological data from the shuttle radar mission topography (STRM) enabled us to understand and describe local features. Exploration of water use (drinking and/or corporal (hygiene) and/or domestic (cooking, washing-off., etc.) uses) in the households in the vicinity of the groundwater water sampling sites was conducted in March 2018. Information on local water uses, waste water management and sanitation was collected to understand the specificities of this sub-Saharan African capital city. For an overview of the occurrence of pharmaceuticals, surface water and groundwater in the upper Méfou basin that drains Yaoundé and its outskirts were monitored in February/March, 2018. Given the lack of information on pharmaceutical consumption in Yaoundé, the targeted analytes were selected based on their reported occurrence in the aquatic environment in Sub-Saharan water bodies (Madikizela et al., 2017) on their various physicochemical characteristics and in order to include some metabolites poorly documented. This multidisciplinary approach provides an integrated assessment of human impacts on the aquatic resources linked to the environment and water use features.

II. Material and methods

II.1. Local settings

II.1.1. Location of the study area

The Méfou watershed is located in the Center Region of Cameroon (latitude 3°30' to 3°58'; longitude 11°20' to 11°40'), and covers an area of 840 km^2 (Olivry, 1986). The Mfoundi River is one of the major tributaries of the Méfou River and drains the city of Yaoundé (latitude 3°52'; longitude 11°31') comprising an area of 180 km^2. The Méfou and Mfoundi watersheds are described in detail in a previous paper (Branchet et al., 2018). The region has a Guinean climate characterized by two rainy seasons (March-June and September-November) and two dry seasons (December-February and July-August). Annual rainfall is around 1,600 mm (Moffo et al., 2016; Olivry, 1986; Srang, 1972). The study area comprised the upper Méfou watershed and the Mfoundi watershed (Figure 1).

The source of Yaoundé's tap drinking water is surface water. The Camwater catchment station is located on the Méfou artificial lake in the upper part of the Méfou basin and is surrounded by a peri-urban area. A second water catchment is located downstream from the confluence between the Méfou and Nyong Rivers.

In addition, shallow aquifers are tapped to supply water to the local population for different uses (domestic use, drinking water, irrigation, etc.). This tapped groundwater is constituted by the upper unconfined porous aquifer in the lateritic soil.

The basement comprises metamorphic rocks including paragneiss, migmatite gneiss and schists with the abrasion products laterites on the top. Soils at the top of the hills and on the slopes are ferralitic. The soils in the lowlands are hydromorphic clay and sand and originate from slope colluvium and river alluvium (Bachelier, 1959). Networks of fractures and fissures enable the existence of unconfined porous ferralsol aquifers (Bon et al., 2016). In this sandy silty clay, fluctuations in the water table range from 0.49 m in the valleys to 1.3 m on the plateau according to Ntep et al. (2014). Deeper aquifers (> 20 m) are located in the fractured gneiss.

Thus "groundwater" from wells, boreholes and sources is from surface water infiltrated in the upper meters of soil up to 20 meters according to litterature (Kringel et al., 2016). In the study area, the mean well depth is 4.2±3.1 meters (n=21 wells). These aquifers are known to receive inputs from innumerable pit latrines and septic tanks (Tabué Youmbi et al., 2009) which has not been listed during the present work.

II.1.2. Sub-watershed characterization

Available data on the study area were used to assess land use, geomorphological and hydrological specificities. The data came from a digital elevation model (DEM) from the shuttle radar topographic mission (SRTM) (Farr et al., 2007) at a

resolution of 30 m for geomorphology (slope, elevation, topography) and hydrology (lag-time, flow velocity); the European spatial agency climate change initiative (ESA-CCI) (ESA, 2016) for land use at resolutions of 20 m and 300 m depending on the shapefiles; and open access data concerning buildings from the Open Street Map project (OpenStreetMap Contributors, 2018); completed by field measurements.

The main land uses in the study area (source ESA-CCI, 2015) are forests (39%), built up areas (27%) and croplands (24%) (Figure 1). Based on the SRTM data, the upper Méfou and Mfoundi watersheds were divided into 10 sub-watersheds (Table 1 and Figure 1). These sub-watersheds are characterized by their peri-urban or urban environment. The peri-urban sub-watersheds are PU1 (Etoud Village), PU2 (Camwater), PU3 (Ossongoé), PU4 (Oil Palm) and PU5 (Nsimalen). The urban sub-watersheds are U1 (Merchandise station), U2 (Sofavinc), U3 (Messamendongo), U4 (Melen) and U5 (Biyeme-Assi).

Table 1: Links between the names of the sub-watersheds and the names of the surface and groundwater sampling sites; and related rivers and environment

Sub-watersheds were named according to their environment, i.e. PU_x: peri-urban or U_x: urban. For groundwater sampling sites, B corresponds to boreholes, S to springs and W to wells. PU2 was sampled upstream (PU2-Up) and downstream (PU2-Do) the raw water treatment at the Camwater station. Site U4 was sampled upstream (U4-Up) and downstream (U4-Do) from the point source of the university hospital effluents (around 0.5 km from the university hospital)

Numbers in brackets (n=x) refer to the number of samples taken at a given site. Groundwater was sampled once during the water use survey (see II.1.3).

The last column in the table lists the names of sampling points used in the related study by Branchet et al. (2018) on pesticide contamination of the Méfou watershed.

Name of the sub-watershed in the present study	**Name of the surface water sampling site (n=1 to 3)**	**Name of the groundwater sampling site (n=1)**	**Name of the river/tributary**	**Environment**	**Name of the sampling point used to monitor pesticides in Branchet et al. (2018)**
PU1 - Etoud Village	/	PU1-B1	Méfou	Peri-urban	Méfou1
PU2 – Camwater	PU2-Up (n=1) PU2-Do (n=1)	/	Méfou	Peri-urban	Méfou2
PU3 – Ossongoé	PU3 (n=2)	/	Ossongoé (Méfou tributary)	Peri-urban	/
PU4 - Oil Palm	PU4 (n=2)	PU4-B1	Mfoundi	Peri-urban	Mfoundi4
PU5 – Nsimalen	PU5 (n=2)	PU5-B1	Méfou	Peri-urban	Méfou5
U1 - Merchandise station	U1 (n=3)	U1-S1	Mfoundi	Urban	Mfoundi1
U2 – Sofavinc	U2 (n=3)	U2-B1	Mfoundi	Urban	Mfoundi2
U3 – Messamendongo	/	U3-B1	Mfoundi	Urban	Mfoundi3
U4 – Melen	U4-Up (n=3) U4-Do (n=3)	U4-W1 U4-W2	Olézoa (Mfoundi tributary)	Urban	/
U5 – Biyeme-Assi	U5 (n=3)	U5-B1 U5-B2 U5-W1	Biyeme (Mfoundi tributary)	Urban	Biyeme1

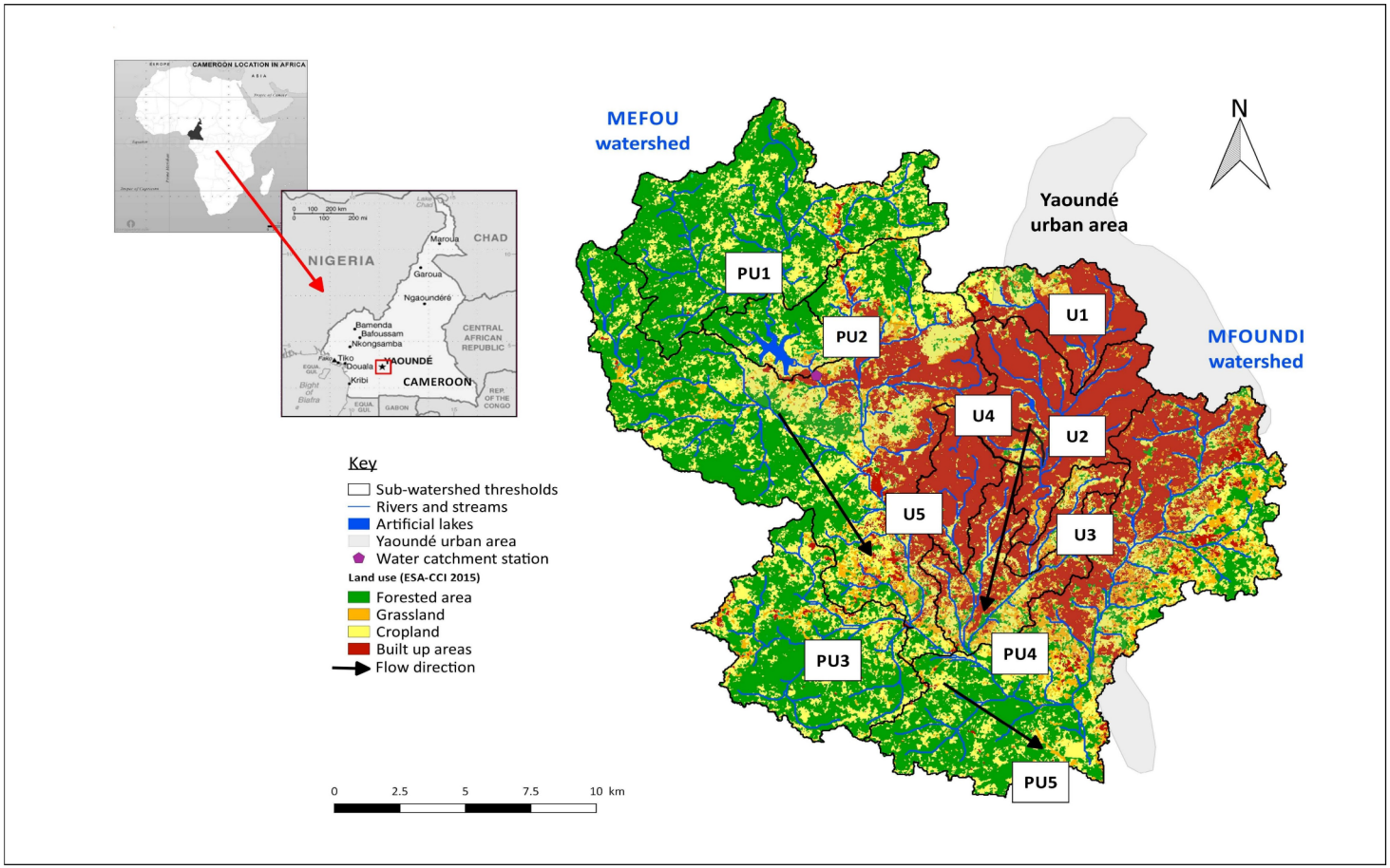

Figure 1: Land use (ESA-CCI 2015; resolution 20 meters), hydrographic network (SRTM 2014), Yaoundé urban area (Open Street Map) and the 10 sub-watersheds of the upper Méfou and the Mfoundi watersheds studied

PU_x: peri-urban; U:$_x$urban environment of the sub-watershed concerned. The map of the whole Méfou watershed is available in (Branchet et al., 2018).

II.1.3. Design of the water use survey

A qualitative exploration on water use of the general population of Yaoundé was conducted in March 2018. The local population in the vicinity of the surface and groundwater sampling points of the 10 sub-watersheds was surveyed. Systematic sampling was done of all the households located next to the water sampling point, and then of every two or three houses, depending on local features. People were interviewed face to face. The head of the household was questioned but if he was absent, his wife (or family member that was more than 15 years old, or the cleaning lady) was questioned. Between two and 15 households were surveyed depending on the location, giving a total of 73 households.

The survey tool was a questionnaire adapted from (Kringel et al. 2016) and from (INS et BGR 2013). It is based on the knowledge, aptitude, perception and behaviour (KAPB) (WHO, 2008)survey towards the urban environment. The survey questionnaire comprised five sections: (i) the socio demographic characteristics of the household including the housing standing as defined in the literature (Franqueville, 1984; Tanawa et al., 2002; Tchotsoua, 1994), (ii) water use: water source, water treatment and identification of potential sources of pollution, (iii) sanitation: type of toilet, excreta management, (iv) perception of pollution and (v) self-rated perception of health: health problems and pharmaceutical consumption and waste management. Questions concerning water use focused on drinking water and domestic water uses.

Participation to the survey was volunteer and the respondents could withdrawal at any time during the questionnaire administration. We insured that the collected data will be anonymous and particularly that: the name of the respondents were not written down; the paper questionnaires will be kept in a closed and secured wardrobe, beyond reach of the public, during the research duration (2 years) then during 5 years. Then, they will be destroyed.

II.2. Environmental analysis

II.2.1. Sampling sites and sampling procedure

Sampling sites were located in 10 sub-watersheds selected for their spatial distribution across the hydrographic network (Table 1 and Figure 2). For surface water, five sampling sites (U1, U2, U4up, U4-Do and U5) were located on urban rivers (three sites on the Mfoundi River, one site on the Biyeme River and one site on the Olézoa River). Five sampling sites (PU2 to PU5) were located on peri-urban rivers (three sites on the Méfou River, one site on the Ossongoé River and one site on the Mfoundi River). Every surface water outlet in the sub-watersheds was sampled for pharmaceutical analyses except PU1, U3 and U4 sub-watersheds. At U4, the Olézoa River was sampled upstream (U4-Up) and downstream (U4-Do) from where the university hospital discharges its effluent into the Olézoa River. PU2 corresponds to the Camwater water treatment station on the Méfou River. Samples water were collected from the influent (raw

water) entering the station (PU2-Up) and from the effluent (treated water) leaving the station (PU2-Do).

Eleven sites corresponded to sampled groundwater (seven boreholes, three wells and one spring). No wells, boreholes or sources were present at PU2 and PU3 so we couldn't sampled groundwater at these sites. In U4 (Melen) and U5 (Nsimalen), several groundwater sites were used for drinking, corporal and domestic uses so two wells in U4, and two boreholes and one well in U5 were sampled (Table 1).

Surface water samples were collected on several occasions (one to three times depending on local authority authorization) in the rainy season in February and March 2018 (Table 1). Groundwater samples were collected once in March 2018. Glass bottles were used to retrieve grab samples. Before use, the bottles were cleaned with a potassium hydroxide solution (Neodisher® LM3 from Dr.Weigert, France) and Milli-Q water to avoid cross contamination. At the river sampling sites, grab samples were retrieved at a depth of about 1 meter. Water from wells was collected in the bucket that was usually used, after first rinsing it. In the case of boreholes, the pump was left running until we were sure of reaching the groundwater to avoid sampling water that had accumulated in the pipes. Water from sources were directly collected in sampling glass bottles, after first rising it. After sampling, the glass bottles were immediately stored in the shade at 4 °C and treated within 24 h. All water samples were analyzed in duplicate.

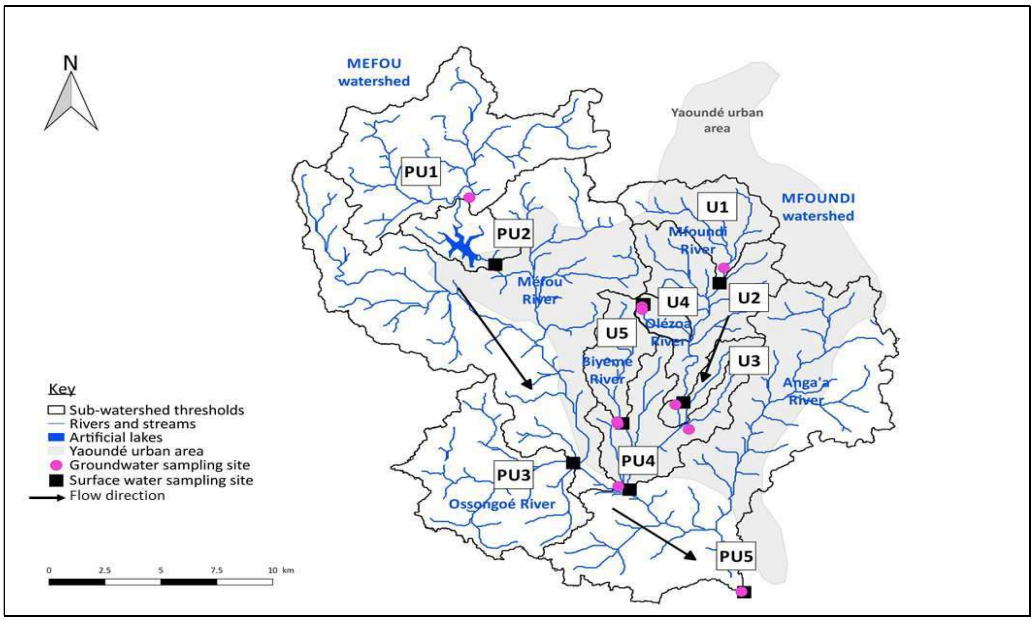

Figure 2: Location of surface and groundwater sampling sites on the 10 sub-watersheds of the upper Méfou and Mfoundi watersheds

U_x sites are located on the Mfoundi River, PU_x on the Méfou River, U4 on the Olézoa River, U5 on the Biyeme River. PU3 is located on the Ossongoé River

II.2.2. Pharmaceutical analysis

Chemicals and materials

Fifteen pharmaceuticals belonging to eight different therapeutic classes and nine metabolites were selected and corrected by fourteen internal standards with purities equal to or greater than 98% (Table 2).Individual stock standard and isotopically labelled standard solutions were prepared at a concentration of 100 mg/L in methanol, with the exception of ofloxacin, ciprofloxacin and ofloxacin-d3 that were dissolved in methanol: water (50:50, v/v) by adding 0.2 % hydrochloric acid. All the standard solutions were stored at -20 °C. Working solutions (range of 5-500 ng/L), containing all the pharmaceuticals, were prepared by appropriate dilution of the stock solution in methanol. A mixture with all isotopically labeled internal standards was prepared at a concentration of 1 mg/L in methanol. Ultrapure water was generated by a Simplicity UV system from Millipore (Bedford, MA, USA) with a specific resistance of 18.2 MΩ.cm at 25°C. HPLC/MS-grade solvents (methanol and acetonitrile - ACN) were purchased from Carlo Erba (Val de Reuil, France). Formic acid (purity, 98%) was purchased from Fisher Labosi (Elancourt, France). All chromatographic solvents were filtered through a 0.22 µm nylon membrane filter (Nylaflo^{TM}, Michigan, USA). Glass-fiber filters (GF/F) (with 0.7 µm pore size) purchased from Whatman (Maidstone, UK) were used to filter the water samples. Oasis$^{®}$ HLB 6cc (200 mg) cartridges, purchased from Waters Corporation (Mildford, USA), and a Visiprep^{TM} DL Solid Phase Extraction (SPE) vacuum manifold purchased from Supelco (Bellefonte, USA) were used for solid phase extraction. Nanosep® MF 0.22 µm centrifuge filters purchased from PALL Life Sciences (Michigan, USA) were used to filter the extracts before chromatography injection.

Water sample extraction and analysis

Filtered surface and groundwater samples (500 mL) were spiked with the mixture of isotopically labeled standard to reach a final concentration of 100 ng/L. Waters were extracted using Oasis HLB cartridges, previously conditioned with (2x5 mL) of methanol followed by (2x5 mL) of ultra-pure water at a flow rate of approximately 5 mL/min.

The cartridges were rinsed with 5 mL ultrapure water and dried under vacuum for 1 h. Analytes were eluted with 10 ml of methanol. Extracts were evaporated to dryness at 35 °C under a gentle stream of nitrogen, reconstituted with 200 µL of acetonitrile: ultrapure water (2:98, v/v) and filtered before analysis.

Analyses were carried out on an Exactive LC-HRMS (Thermo Fisher Scientific) using an HPLC Accela 1250 Pump and a degasser (Thermo Fisher Scientific, San Jose, CA, USA) equipped with an analytical column (KinetexBiphenyl, 100 x 2.1 mm; 2.6 µm particle size, Phenomenex). ACN and water were used as mobile phases. Addition of 0.1% formic acid was preferred in positive ionization mode. The optimal separation was achieved at a flow rate of 400 µL/min. The

optimized gradient elution program started with 2% of ACN isocratic for 0.5 min, increased to 50% of ACN at 12 min, followed a linear gradient to 100% ACN at 14 min, remained at this level for 3 min, and then decreased to 2% ACN for equilibration of the column for 7 min. The injection volume was set to 10 µl. The Exactive HRMS was turned to a mass resolution of 10,000 (FWHM, m/z 200) with a mass spectrum range of 50-650 m/z. A heated electrospray ionization probe (HESI) source in positive (pos) and negative (neg) mode was used. The HESI parameters were as follows: heater temperature 200 °C; capillary temperature 275 °C; electrospray voltage 4 kV; sheath gas flow 55 arbitrary units; auxiliary gas flow 10 arbitrary units. The following parameters were used in positive and negative ionization modes, respectively; capillary voltage 35V and -50V; tube lens voltage 110 V and-100 V; finally skimmer voltage 25 V and -16 V. "All ion fragmentation" MS/MS mode was applied with high energy collision dissociation (HCD) cell set to 10 and 20 eV. Analytical results were calculated with Thermo Scientific Xcalibur software. Each compound was identified according to: (1) retention time; (2) mass accuracy (max 5 ppm deviation) of protonated $(M-H)^+$ or deprotonated $(M-H)^-$ molecules in MS/MS mode; (3) identification of at least one ion fragment at a mass accuracy < 5 ppm in MS/MS mode and (4) ion ratio fulfilled between the ion fragment and the parent ion for each molecule.

Quality assurance/quality control

The linearity of the method was estimated in both solvent and matrix (using ultrapure water), with a blank test and calibration curves (6 levels) spiked with from 2 to 200 ng/L of the compounds including a fixed amount of internal standard. Absolutes recoveries, matrix effects and repeatability of the method were evaluated by spiking ultrapure water with 100 ng/L of all compounds (n=5). The LOD and LOQ of each analyte were determined as the concentration resulting in a signal to noise ratio of 3 and 10 respectively. Before each analysis and during the sequence, a standard mixture (100 ng/L including internal standards) of the molecules of interest and a blank mobile phase were analyzed to check the LC-MS/MS performance.

Table 2: Therapeutic classes, internal standards, supplier, purity, ionization type, quantification and confirmation ions, instrumental LODs and LOQs, methods LODs and LOQs and absolutes recoveries observed for each molecule in LC-MS Orbitrap

Therapeutic classes	Molecules[1ou 2]/ internal standards	Supplier	Purity	Ionisation type	Quantification ion (energie eV)		Confirmation ion (energie eV)		RT (min)	LOD^{inst} (pg)	LOQ^{inst} (pg)	LOD^{Meth} (ng/L)	LOQ^{Meth} (ng/L)	Absolute Recovery[3] (%)
Anti-epileptic	Carbamazepine[1]/Carbamazepine D8	Sigma-Aldrich	≥99.0%/ ≥98.5%	+	**237.1022**	10	**194.0962**	20	9.30	10	30	5	10	112±15
Analgesic/anti-inflammatory and their metabolites	Codeine[1]/Codeine D6	Sigma-Aldrich	99.9%/99.2%	+	**300.1594**	20	**243.1010**	20	4.75	5	10	2	10	53±3
	Codeine 6βD glucuronide[2]/ Codeine 6βD glucuronide D3	Sigma-Aldrich/LGC	>99.9%/99%	+	**476.1915**	20	**300.1587**	20	4.53	30	50	5	10	92±9
	Ibuprofen[1]/Ibuprofen D3	Sigma-Aldrich	≥98.0%	-	**159.1170**	10	**205.1234**	10	11.31	10	20	25	50	90±15
	1-hydroxy-ibuprofen[2]/Ibuprofen D3	LGC/Sigma-Aldrich	99.3%/ ≥98.0%	-	**157.1010**	10	**221.1183**	10	6.80	10	20	10	25	94±9
	carboxy-ibuprofen[2]/Ibuprofen D3	Sigma-Aldrich	99.4%/ ≥98.0%	-	**191.1070**	10	**235.0975**	10	1.78	10	50	2	10	98±6
	Ketoprofen[1]/Oxazepam D5	Santa Cruz Biotechnology/ Sigma-Aldrich	>99%/99.4 %	-	**197.0600**	10	**253.0870**	10	8.83	10	20	5	10	92±17
	Diclofenac[1]/Diclofenac D4	LGC	99.5%/98%	-	**250.0190**	10	**252.0160**	10	10.72	10	20	10	15	80±15
	Acetaminophen[1]/Acetaminophen D4	Sigma-Aldrich	>99.9%/99.8%	-	**150.0560**	10	**107.0360**	20	2.96	10	20	5	10	88±12
Antibiotics/anti-infective	Ofloxacin[1]/Ofloxacin D3	LGC	99.7%/98.5%	+	**362.1511**	10	**318.1604**	20	5.96	5	10	5	10	57±7
	Sulfamethoxazole[1]/ Sulfamethoxazole D4	LGC	99.8%/99.5%	-	**156.0120**	20	**252.0448**	10	7.17	5	10	2	5	56±8
Benzodiazepine and their metabolites	Diazepam[1]/Diazepam D5	LGC	99.9%/99.5%	+	**285.0789**	20	**257.0836**	20	11.29	5	10	5	10	106±15
	Oxazepam[1,2]/Oxazepam D5	LGC/Sigma-Aldrich	99.9%/99.4 %	-	**285.0436**	10	**257.0480**	10	9.87	5	10	2	10	83±21
	Oxazepam glucuronide[2]/ Oxazepam glucuronide D5	LGC	99%/98.2%	+	**287.0578**	20	**463.0903**	10	8.28	30	50	5	10	103±5
	Lorazepam[1]/Oxazepam D5	LGC/Sigma-Aldrich	99.9%/99.4 %	-	**283.0280**	10	**319.0050**	10	10.05	3	10	5	10	85±23
Antidepressant	Venlafaxine[1]/Venlafaxine D6	Sigma-Aldrich/LGC	≥98.5%/98.7%	+	**278.2114**	10	**260.2003**	10	7.45	5	10	5	10	95±8
Lipid lowering and their metabolites	Pravastatin[1]/Ibuprofen D3	LGC/Sigma-Aldrich	98.9%/≥98.0%	-	**423.2388**	10	**321.1710**	20	7.87	10	20	10	25	32±2
	Fenofibric acid[2]/Acetaminophen D4	Sigma-Aldrich	≥98.0%/99.8%	-	**231.0210**	20	**233.0180**	20	8.20	10	20	2	5	87±14
Beta-blockers	Atenolol[1]/Atenolol D7	LGC/Sigma-Aldrich	99.3%/≥95%	+	**267.1703**	10	**190.0861**	20	3.42	5	10	<2	5	102±5
	Propanolol[1]/Atenolol D7	LGC/Sigma-Aldrich	99.9%/≥95%	+	**260.1645**	10	**183.0801**	20	8.54	5	10	25	75	99±38
Opiate substitutes and their metabolites	Buprenorphine glucuronide[2]/ Codeine 6βD glucuronide D3	Sigma-Aldrich/LGC	99.2%/99%	+	**644.3429**	20	**468.3099**	20	7.38	30	50	10	10	91±15
	Norbuprenorphine[2]/ Norbuprenorphine D3	Sigma-Aldrich	99.1%/99.7%	+	**414.2639**	20	**414.2639**	10	7.52	50	100	10	50	82±41
	Norbuprenorphine glucuronide[2]/ Codeine 6βD glucuronide D3	Sigma-Aldrich	98.2%/99%	+	**590.2960**	20	**414.2632**	20	5.60	30	50	5	15	85±2

[1]correspond to parent compounds; [2]correspond to metabolites; Absolute Recovery[3] calulated without correction by internal standard.

III. Results and discussion

III.1. Characterization of the sub-watersheds

III.1.1. Hydro geomorphological characterization

Differences in hydro geomorphology (Supplementary Material), land use (Figure 1) and anthropic pressures were observed between peri-urban and urban sub-watersheds.

The steepest basin slopes (11-21%) and lowest flow velocity (0.1-0.4 m/s) were measured in the peri-urban sub-watersheds. PU1 and PU2 had the highest basin slopes (21% and 14% respectively) and the highest related hydrologic response times (5-10 hours). The north-western peri-urban part of the study area has steep slopes but relatively natural river banks and meandering rivers. The peri-urban sub-watersheds are mostly covered by woodland (9-72%), 21-31% croplands and 2-53% built-up area. Between 1992 and 2015, built-up areas increased by 29% at PU4 and by 10% at PU5 (ESA-CCI data). The urban area only extends to the south-east because of the natural barrier formed by the relief in the north-western part of the basin that limits urbanization (Dauvergne, 2011).

In contrast, although the basin slope of the urban sub-watersheds ranges between only 11% and 13%, these watersheds have the highest flow velocity (0.2-0.8 m/s) and relatively short hydrological response (<5-10 h). Urban sub-watersheds comprise 27-88% of built-up area and 6-24% of croplands. In particular, U1, U2 and U5 have more than 70% of impervious (built-up) area (ESA-CCI 2015) (Figure 1). The urban area crossed by the Mfoundi River is currently channeled with artificial river banks to reduce recurrent floods in downtown Yaoundé; this increased urban river flow velocities and reduced the extent of wetlands in the south of the Méfou basin (Moffo et al., 2011). Assuming the building density in Open Street Map 2017 data reflects population density, the upper Mfoundi watershed is under the highest anthropic pressure with high building density in particular at U5 (1,551 buildings/km^2), U2 (1,087 buildings/km^2) and U1 (1,079 buildings/km^2) (Figure 3). The city dynamics could emphasize urbanization in the study area. Indeed, according to ESA-CCI data, built up area increased from 21% to 27% while forested land decreased from 19% to 15% from 1992 to 2015.

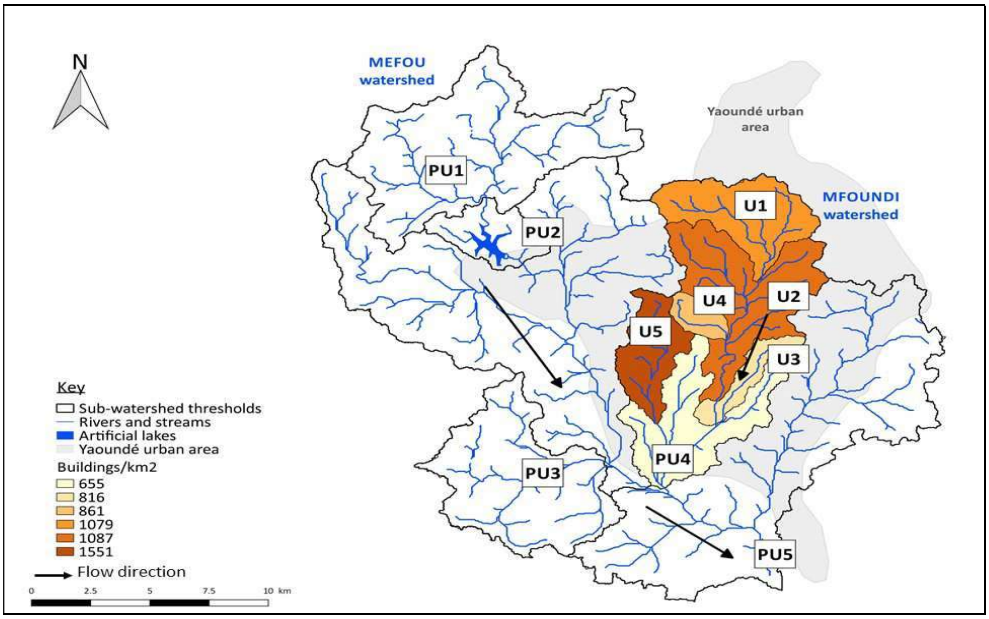

Figure 3: Map showing building density in the Mfoundi sub-watersheds (Open Street Map 2017, ESA-CCI 2015)

No Open Street Map data were available for the peri-urban sub-watersheds shown in grey on the map, which consequently only provides data for the urban Mfoundi basin sub-watersheds delimited in Figure 1.

Urban areas are subject to anthropic pressure. In particular, reports in the literature state that there are only four waste water treatment plants (WWTP) in Yaoundé for almost two millions inhabitants. The type of WWTP treatments are activated sludges, lagoon system, sand filtration or macrophyte-based waste water treatment system. According to Naah (2013), the capacity of the WWTP were comprised between 650 and 30,000 population equivalent but the truly functioning WWTP were covering around 6,300 population equivalent in total which represent 0,3% of Yaoundé population. Consequently most untreated domestic wastewater is released into the surface waters of the upper Méfou basin (Kenmogne et al., 2010; Wethé et al., 2003). Microbiological analyses revealed fecal contamination of all urban streams (Djuikom et al., 2008, 2006). In Yaoundé, landfills are constituted by the unemerous and sometimes ephemeral waste heaps distributed in all the urban area. These waste heaps are mostly constituted by domestic solid waste that has been reported as an additional pharmaceutical contamination source adding to domestic wastewater (Bu et al., 2016; Peake et al., 2015).

The Méfou watershed is also subject to anthropic pressure due to urbanization, mostly in the Mfoundi sub-watershed (U1-U5). Urbanization accentuates the natural tendency of the relief to favor rainfall-runoff events because it increases the extent of impervious land surface (Moffo et al., 2011). It may also accelerate upstream to downstream water flow by channeling the streams in the urban area. Runoff could also be at the origin of the drainage of contaminants, i.e. pharmaceuticals, pesticides, bacteria, adsorbed on urban surfaces (Blanchoud et al., 2007; Wilkinson et al., 2017).

The natural features (elevation, slope, hydro-geomorphology) favor rainfall-runoff processes in particular in the north-western part of the peri-urban area (PU1 and PU2). The combination of these hydrological features, the lack of sanitation and the continuous increase in built up areas raises concerns about sources of contamination in particular sources of pollutants including pharmaceuticals in wastewaters and landfills that can reach surface waters.

III.1.2. Wastewater management and groundwater characterization

Disparities were observed in housing quality, water use and wastewater management around the urban water sampling sites during the interviews on water use. At U1, U2 and U5, 43-47% of the respondents lived in low quality housing; in particular at U4, where the proportion increased to 67%. On the other hand at U3, only 18% of respondents lived in low quality housing, and 36% and 27% lived in medium and high quality housing, respectively. Low quality housing implies no proper infrastructure enabling access to water and sanitation (OMS and ONU-Habitat, 2010).

Considering the water use survey as a whole, pit latrines were reported as the main type of sanitation (36-79% of households). Again U3 stood out as 55% of the respondents reported using a WC (toilets with water flush) and only 36% pit-latrines. The population survey showed that 80% of the households throw out their wastewater in their

immediate surroundings (into drains, rivers and yards). A total of 71% of the respondents in the water use survey said they throw away drugs whose use-by-date has expired into landfills and 11% into pit latrines because no system for recycling of expired drugs exists in Cameroon like the Cyclamed network in France, for example.

The U4 survey site was also where drinking water shortages were the most frequent (67%) followed by U2 with 64% of households concerned. At U3, only 18% of the respondents reported drinking water shortages. The most regularly flooded homes were located in U2, with 82% of the respondents affected. Around the sampling points, 68% of the all respondents reported they used groundwater for drinking (45% boreholes, 13% wells, 10% springs); 78% that they used groundwater for domestic purposes including cooking and washing clothes (12% boreholes, 65% wells, 1% springs); and 79% for bathing, personal hygiene, etc. (14% boreholes, 62% wells, 3% springs). Differences were observed in the urban area in the sources of groundwater used for drinking water. In particular in the U4 district, 100% of the respondents reported they relied on groundwater for drinking, 43% from boreholes and 57% from wells. In the U3 district, a very high proportion (91%) of the respondents reported they used boreholes for drinking water. Water is treated if the groundwater comes from a well in 70% of the households surveyed; whereas drinking water from boreholes and springs is less frequently treated (43% and 24%, respectively). Information concerning the type of treatment was difficult to obtain, but 14% of the respondents said they used filtration and 8% bleach to eliminate bacteria or other pollutants.

The well at U4 (U4-W1) was typical of wells in Yaoundé. In particular, this well can be qualified as “partially equipped” because the safety slab is cracked and a latrine is present at a distance of less than 5 meters from the well. In contrast, boreholes are generally “well equipped” because they are completely concreted and access is restricted. Springs that emerge from rocks are poorly equipped; only a platform is installed to allow water collection. The immediate surroundings of groundwater supply points are crucial to limit contamination from pollutants from the soil through runoff or infiltration. It is usually recommended that a protected area is established around wells (i.e. at least ten meters from a latrine and a soil thickness of at least four meters between the bottom of the latrine and the aquifer) (Tabué Youmbi et al., 2009). This is not always the case in Yaoundé in particular in unplanned districts (INS and BGR, 2013; Kringel et al., 2016; Takounjou et al., 2009; Youmbi et al., 2013).

These observations are in agreement with observations made in a previous study of the nitrogen and phosphorus mass balance in Yaoundé groundwater (Kringel et al., 2016). First, these authors also reported that waste management based on pit latrines and septic tanks increases the likelihood of groundwater contamination by wastewater. They provided evidence that the amount of wastewater could recharge the aquifer leading to an “anthropic groundwater type”. At certain locations, wastewater can infiltrate the porous ferralsol aquifer. The authors argued that wastewater can

determine groundwater quality. Their study confirmed that the management of wastewater we identified around our sampling points is widespread in Yaoundé and that, in general, the aquifers of the urban sub-watersheds are likely to receive contaminants from human excreta i.e. fecal bacteria and possibly also pharmaceuticals. The widespread use of groundwater accentuates the importance of monitoring groundwater.

III.2. Pharmaceutical contamination of surface and groundwater and related issues

Pharmaceutical detection and quantification

Some pharmaceuticals are widely used as markers of wastewater inputs, for example carbamazepine for surface waters (Pongmala et al., 2015); sulfamethoxazole, sulfanilamide and carbamazepine for groundwater, as in the study case of Varanasi in India (Lapworth et al., 2018); atenolol, carbamazepine and diclofenac in different catchments in Switzerland (Epting et al., 2018).

In this study, among the 23 molecules of interest, eight pharmaceuticals belonging to four therapeutic classes (anti-epileptics, NSAIDs/analgesics, antibiotics/anti-infective and beta-blockers) were detected at least twice across all samples (Table 3). Pharmaceuticals belonging to benzodiazepines, antidepressants, lipid-lowering drugs and opiate substitutes were not detected either in groundwater or in samples of surface water.

The antiepileptic carbamazepine and the analgesic acetaminophen were the most frequently detected and quantified compounds in surface waters (Figure 4). Carbamazepine was detected and quantified in up to 100% of water samples. Acetaminophen was also detected in up to 100% and was quantified in up to 85%. Carbamazepine is usually taken as a continuous treatment for epilepsy and trigeminal neuralgia. Once discharged into wastewaters and/or in effluents from WWTP - from which it is poorly removed (<10%) **(Hai et al., 2018)** by conventional treatment - it is relatively persistent and widespread in the aquatic environment (Andreozzi et al., 2002; Hai et al., 2018). In the surface waters of Yaoundé and due to the almost total absence of sanitation, carbamazepine remains a relevant anthropogenic tracer. Acetaminophen belongs to the therapeutic class of NSAIDs which is the most widely consumed class of drugs in the world. They are easy to acquire and are included in the formulation of several medical drugs combined with other active ingredients, which may partly explain their wide occurrence in water (He et al., 2017) and consequently the presence of acetaminophen in the water samples.

Differences in pharmaceutical occurrence were observed between peri-urban and urban sub-watersheds in addition to differences in the type of water (surface and groundwater) (Table 3 and Figure 4).

Among the targeted compounds, the NSAID/analgesic codeine, the antibiotic ofloxacin and the beta-blocker atenolol were detected and quantified in surface waters in the urban area but not in the surface waters in the peri-urban area. All

the compounds detected in the peri-urban surface waters were also found in the urban surface waters. The fewest molecules were detected and quantified in the subwatershed PU2 (at the Camwater treatment station).

Carbamazepine was detected and quantified in 100% of the water samples in the urban area and in 75% of the water samples in the peri-urban areas. Acetaminophen was detected in 100% of the samples in both the urban and the peri-urban areas but was more frequently quantified in the urban area (85%) than in the peri-urban area (75%). Ibuprofen and diclofenac followed the same trend with up to 95% and 75% of detection frequency in the urban area and up to 55% and 45% of quantification frequencies, respectively. In the peri-urban area, their detection frequencies were 75% but diclofenac was quantified more (75%) than ibuprofen (50%). The anti-infective sulfamethoxazole differed, it was more often quantified in the peri-urban area (50%) than in the urban area (6%).

Pharmaceutical concentrations

In terms of surface water contamination levels, urban sub-watersheds (U1 to U5) were more polluted with pharmaceuticals (range < 2 to 5,660 ng/L) than peri-urban sub-watersheds (PU1 to PU5) (range < 2 to 367 ng/L).

The highest concentrations of NSAIDs/analgesics acetaminophen, diclofenac, ibuprofen were measured in urban areas, with median concentrations of 24-2,994 ng/L, <10-318 ng/L and 25-259 ng/L, respectively. The highest concentrations were measured at the U1 sub-watershed, with a peak concentration of acetaminophen of 5,660 ng/L. Peak concentrations of ibuprofen were 516 ng/L at U2 and for diclofenac 419 ng/L at U1. Although it was detected in all the samples, carbamazepine was quantified between 73 ng/L and 163 ng/L (median concentrations) with the highest concentration (193 ng/L) measured at U5.

In contrast to urban sub-watersheds, lower concentrations were measured in the peri-urban sub-watersheds. Codeine and acetaminophen were the only two molecules detected at PU2 (Camwater treatment station), both in the raw and in the treated surface water resource of the Méfou River. The maximum measured concentrations in PU3 sub-watershed were 72 ng/L of ibuprofen, 30 ng/L of diclofenac, 15 ng/L of carbamazepine and 14 ng/L of acetaminophen. The highest concentrations were measured at PU4 with median concentrations of ibuprofen, diclofenac and sulfamethoxazole of 224 ng/L, 166 ng/L and 120 ng/L, respectively. At PU5, median concentrations at Nsimalen were 11 ng/L, 35 ng/L, 58 ng/L and 62 ng/L respectively for acetaminophen, carbamazepine, sulfamethoxazole and diclofenac.

At this stage, we can confidently affirm that the surface waters of Yaoundé are contaminated by relatively higher levels of pharmaceuticals in urban wastewaters than in the peri-urban area whose surface waters may be under less anthropic pressure (Figure 1 and Figure 3). The results of this monitoring campaign can be put in parallel with building density (Figure 3). The highest measured concentrations and peak contaminations were evidenced in particular in U1 (highest

global pharmaceutical concentrations), U2 (diclofenac peak concentration) and U5 (carbamazepine peak concentration) which are the sub-watersheds with the highest building density (861, 1087 and 1551 buildings/km2 respectively). This situation is in agreement with anthropic pressures from domestic wastewaters and adds supplementary information on these "pollution hotspots" previously identified in Yaoundé (Branchet et al., 2018).

In the PU4 sub-watershed; the environment is wetlands and oil palm plantations, however it drains the whole urban Mfoundi watershed, explaining why at this peri-urban point, measured concentrations were higher than in PU2, PU3 and PU5. The PU5 sub-watershed receives waters both from the peri-urban area and from the urban area because it is at the downstream confluence of the upper Méfou River and of the Mfoundi River. We expected pharmaceutical concentrations to be higher than in PU2 and PU3 because of the discharge of the urban contamination into the Méfou River as previously reported (Branchet et al., 2018). However concentrations were the same as in PU3 for example, which may be explained by dilution.

In contrast to the peri-urban sub-watersheds, the U1, U4 and U5 urban sub-watersheds were affected by groundwater contamination. The highest concentrations were of diclofenac and sulfamethoxazole, with concentrations ranging from 476 to 518 ng/L and 69 to 1285 ng/L, respectively. The most polluted sub-watershed was U4 due to contamination of the U4-W2 well with carbamazepine (up to 335 ng/L), the diclofenac (up to 518 ng/L) and acetaminophen (up to 111 ng/L) followed by sulfamethoxazole (up to 1,285 ng/L). Concentrations of ibuprofen of up to 154 ng/L were quantified in the U5-B1 borehole. Up to 390 ng/L of sulfamethoxazole was measured in the U5-B2 borehole and up to 134 ng/L in the U5-W1 well. A spring in U1 was contaminated by between 69 and 73 ng/L of sulfamethoxazole.

Questions concerning the fate of pharmaceuticals in the Méfou hydrosystem

Variations in the contamination profiles of surface and groundwater sampling sites raising questions about (i) the mobility of these compounds and (ii) interactions between surface and groundwater in the Méfou hydrosystem.

No relation were found between physico-chemical properties (log Kow and Koc) (Supplementary Material) of the quantified compounds and their occurrence and concentration trends in surface and groundwater. Then, acetaminophen and sulfamethoxazole displayed opposite behaviours. Median acetaminophen concentrations ranged 5 -5,660 ng/L in surface waters whereas the compound was quantified only once in groundwater at a concentration of 110 ng/L. Conversely, sulfamethoxazole concentrations were lower in surface waters (median concentration range < 2 to 120 ng/L) than in groundwater (median concentration range: < 2 to 1,092 ng/L). It has been shown that sulfamethoxazole is a highly mobile compound in surface waters, soils and groundwater. Physico-chemical soil properties (pH, composition) might also affect its fate (Archundia Peralta 2016) suggesting the need for deeper studies on the local environment to

understand its occurrence.

Interactions between surface and groundwater depend on local features (geology, climatic conditions, pedology, etc. and the scale of observation). At the local scale, surface water can recharge groundwater and allow the mixing of the waters at the subsurface thanks to geomorphological and hydrodynamic features. Also the variability of the hydrological conditions over time (turbulent flow, high rainfall, flood, etc.) affect the interactions and flow dynamics between surface water and groundwater. Consequently they remain highly variable and relatively complex (Epting et al., 2018; McLachlan et al., 2017; Vu et al., 2018).

The effect of human activities, in particular pumping groundwater for drinking water, can modify the flow dynamics and cause a reversal in fluxes from groundwater to surface waters or increase vertical migration of contaminants (Lapworth et al., 2018; Vu et al., 2018). Some contaminants including pharmaceuticals can be used as tracers to better define these interactions (Epting et al., 2018). For example, in a case study of the city of Varanasi in India, the concentrations of sulfamethoxazole in the groundwater mirrored those in the surface waters, but were lower and depended on the origin and depth of the groundwater (Lapworth et al., 2018). The vulnerability of the groundwater was underlined. In particular, the authors reported that long-term intensive pumping increased the hydraulic gradient thereby enabling the contaminants to reach deeper aquifers. Pumping also controls the nature of groundwater recharge.

Thus, like in Yaoundé, the increase in groundwater withdrawal through wells and boreholes and the potential for groundwater vulnerability were evidenced. Pharmaceutical concentrations measured in the present study, in particular those of acetaminophen and sulfamethoxazole, add a novel issue concerning surface and groundwater relations as a component of this vulnerability. The need for further study and, for example, the use of modeling (Takounjou et al., 2009) could help explain how the aquifers are recharged by wastewater and local issues related to groundwater contamination.

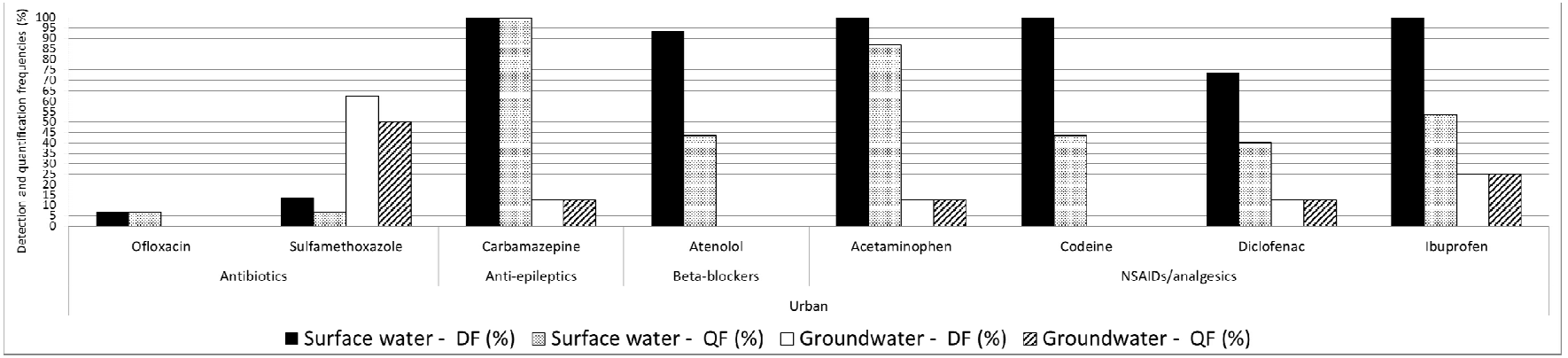

Figure 4: Detection and quantification frequencies of pharmaceutical compounds in surface water and groundwater in urban areas (U1 to U5) during the sampling campaign in March/April 2018 in the upper Méfou watershed

Table 3: Minimum, maximum and median concentrations (ng/L) of the pharmaceutical compounds detected in surface water and groundwater according to the area

SURFACE WATER ng/L																				
Peri-urban area																				
Pharmaceuticals	PU3-Ossongoé				PU2 – Upstream Camwater				PU2 –Downstream Camwater				PU4 – Oil palm				PU5 –Nsimalen			
	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N
Anti-epileptic																				
Carbamazepine	13	17	15	4	< 5	< 5	< 5	2	< 5	< 5	< 5	2	45	82	59	4	27	46	35	4
NSAIDs/analgesics																				
Codeine	< 2	< 10	< 2	4	< 2	< 2	< 2	2	< 2	< 2	< 2	2	< 2	< 2	< 2	4	< 2	< 10	< 2	4
Ibuprofen	71	74	72	4	< 25	<25	< 25	2	< 25	<25	< 25	2	100	367	224	4	< 25	< 25	< 25	4
Diclofenac	29	31	30	4	< 10	<10	< 10	2	< 10	<10	< 10	2	121	212	166	4	59	65	62	4
Acetaminophen	<10	23	14	4	< 5	< 5	< 5	2	< 5	< 5	< 5	2	30	62	33	4	<10	12	11	4
Antibiotics								2				2								
Sulfamethoxazole	< 2	< 2	< 2	4	< 2	< 2	< 2	2	< 2	< 2	< 2	2	115	124	120	4	35	104	58	4
Beta-blockers								2				2								
Atenolol	< 2	< 5	< 2	4	< 2	< 2	< 2	2	< 2	< 2	< 2	2	< 2	< 5	< 2	4	< 2	< 2	< 2	4

Table 3. (continued)

SURFACE WATERS																				
Urban area ng/L																				
Pharmaceuticals	U1 - Merchandise station				U2 – Sofavinc				U4 – Upstream Melen				U4 – Downstream Melen				U5 – Biyeme-Assi			
	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N
Anti-epileptic																				
Carbamazepine	91	136	109	6	42	95	73	6	63	102	74	6	62	99	91	6	39	193	163	6
NSAIDs/analgesics																				
Codeine	<10	14	12	6	< 10	17	13	6	< 10	12	< 10	6	< 10	< 10	< 10	6	< 10	14	<10	6
Ibuprofen	<50	<50	<50	6	< 50	516	<50	6	70	385	190	6	86	414	259	6	< 50	198	<50	6
Diclofenac	189	419	318	6	<15	215	156	6	<10	<10	< 10	6	<10	267	228	6	<10	76	<15	6
Acetaminophen	1728	5660	2993	6	36	1614	155	6	<10	366	24	6	<10	671	192	6	25	615	89	6
Antibiotics																				
Ofloxacin	21	29	25	6	< 5	< 5	< 5	6	< 5	< 5	< 5	6	< 5	< 5	<5	6	< 5	< 5	< 5	6
Sulfamethoxazole	< 2	< 2	< 2	6	< 2	< 2	< 2	6	< 2	< 2	< 2	6	< 2	< 2	< 2	6	80	111	96	6
Beta-blockers																				
Atenolol	< 5	7	< 5	6	< 5	9	< 5	6	< 2	16	< 5	6	< 5	< 5	< 5	6	< 5	12	7	6

Table 3. (continued)

GROUNDWATER																						
Urban area ng/L																						
Pharmaceuticals	U1-S1Merchandise station				U4-W1 Melen				U4-W2 Melen				U5-B1 Biyeme-Assi				U5-B2 Biyeme-Assi				U5-W1 Biyeme-Assi			
	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N	Min	Max	Median	N
Anti-epileptic																								
Carbamazepine	< 5	< 5	< 5	2	< 5	< 5	< 5	2	263	335	299	2	< 5	< 5	< 5	2	< 5	< 5	< 5	2	< 5	< 5	< 5	2
NSAIDs/analgesics																								
Ibuprofen	< 25	< 25	< 25	2	265	276	271	2	< 25	< 25	<25	2	141	154	147	2	< 25	< 25	<25	2	< 25	< 25	<25	2
Diclofenac	<10	<10	< 10	2	<10	<10	< 10	2	476	518	497	2	<10	<10	< 10	2	<10	<10	< 10	2	<10	<10	< 10	2
Acetaminophen	< 5	< 5	< 5	2	< 5	< 5	< 5	2	110	111	110	2	< 5	< 5	< 5	2	< 5	< 5	< 5	2	< 5	< 5	< 5	2
Antibiotics																								
Sulfamethoxazole	69	73	71	2	< 2	< 2	< 2	2	899	1285	1092	2	< 2	< 2	< 2	2	312	390	351	2	116	134	125	2

III.3. Comparison with the international context and local issues

Before the present study, sub-Saharan water bodies were monitored in five different countries (most frequently in South-Africa followed by Ghana, Kenya, Mozambique and Nigeria) for nine therapeutic classes (NSAIDs/analgesics, antibiotics, beta-blockers, lipid-lowering drugs, antiretroviral drugs, antimalarial drugs, anti-epileptics, benzodiazepines and vascular dilatation drugs) (Ebele et al., 2017; Madikizela et al., 2017). The global contamination profile for the common monitored therapeutic classes is similar in previous studies and in the upper Méfou basin, with the predominance of the NSAIDs/analgesics (acetaminophen, codeine, diclofenac, ibuprofen), the anti-epileptic carbamazepine then antibiotics/ anti-infective (ofloxacin, sulfamethoxazole,). Concentration ranges in the present study were slightly lower than those measured in other African surface waters (Madikizela et al., 2017). For example, NSAIDs ranged from a few micrograms per liter to more than 100 µg/L in Kenya (K'oreje et al., 2016) whereas carbamazepine reached 500 ng/L in South Africa (Matongo et al., 2015). However concentrations varied considerably with the local context. Only two studies in Sub-Saharan Africa provide pharmaceutical contamination of groundwater from wells. In Nigeria acetaminophen was measured in the range of 102 ng/L to 18 420 ng/L in wells and diclofenac concentrations ranged 118-13,480 ng/L (Olatunde et al., 2014). In Kenya pharmaceutical concentrations from antibiotics, antiretroviral, NSAIDs and antipsychotic were comprised between 5 ng/L and 1,600 ng/L in wells.

As sources, the local context and drug management and consumption differ among monitored areas, so it is very hard to compare the presence of pharmaceuticals in water bodies in different countries or regions (Jjemba, 2008). It is also risky to link patterns of contamination in rivers to drug consumption because of the spatial scale (local, national) and the season, and the mode of consumption of a drug (i.e. for chronic or infectious diseases) (Thiebault et al., 2017). In Cameroon, the problem is exacerbated by the existence of an informal drug sector (Angbo-Effi et al., 2011; Mendo et al., 2015): the high costs of public health institutions (hospitals, clinics) mean that the poorest population have limited access to health care (Commeyras et al., 2006; OMS and ONU-Habitat, 2010). Consequently, 71% of the population of Yaoundé resort to informal health care units (Geest, 2017) as their main solution or as a complement to the formal pharmaceutical sector and only 30% of formally prescribed drugs are actually taken by the patients (Commeyras et al., 2006). The informal drug sector provides less expensive drugs, but the drugs are of lower quality (concentrations of active substance are uncertain, the types of active substance are uncertain, false drugs, etc.) making an assessment of Cameroonian drug consumption very difficult. However the survey by Commeyras et al. (2006) listed acetaminophen as the most widely prescribed and consumed drug in Yaoundé. This survey and reports in the literature suggest that a cocktail of pharmaceutical compounds are possibly present in-stream, in line with results of monitoring of other sub-Saharan water bodies (Ebele et al., 2017; Madikizela et al., 2017).

« Down-the-drain » modeling approaches are widely used (e.g., LF2000-WQZ (Williams et al., 2009), GRETER-ER (Archundia et al., 2018), STREAM-UE (Lindim et al., 2017), etc.) to predict in stream pharmaceutical concentrations according to the hydrologics, the hydraulics, the consumption patterns and WWTP effluents. However, limited in the specific context of sub-Saharan urban centers, the use of a modeling approach would be limited because, added to the difficult assessment of pharmaceutical consumption, the absence of sanitation makes it hard to include effluents from WWTP in the model. Models would need to be adapted to predict concentrations in water, and to assess environmental risks and health impacts.

High urbanization pressures have environmental impacts (Carvalho et al., 2014; Kotyza et al., 2010), by increasing population vulnerability and related health risks (Dos Santos et al., 2017; Gracia-Lor et al., 2017; Whitehead and Dahlgren, 1991). Living conditions are considered as environmental determinants of health (Whitehead and Dahlgren, 1991). The quality of housing, access to drinkable water and sanitation along with educational level can increase health inequalities among urban populations (OMS and ONU-Habitat, 2010). Our water use survey partly emphasized these inequalities through living conditions and the links between groundwater contamination and use in the urban area raises questions about population exposure and potential health risks in Yaoundé.

Groundwater in three urban sub-watersheds (U1, U4 and U5) was found to be contaminated by pharmaceuticals belonging to the anti-epileptic, antibiotic and NSAID therapeutic classes (**Table 3**). Yet in these areas, the survey population reported using groundwater sources in particular for drinking water purposes. In U1, 47% of the respondents rely on springs, and the spring we sampled was found to contain sulfamethoxazole. In U4, only 8% of the households reported using wells for drinking water, but the wells were contaminated by carbamazepine, ibuprofen, diclofenac and acetaminophen. In U5, 43% of the households used boreholes for drinking water and the one we sampled was found to be contaminated by ibuprofen. Even if health risks due to the presence of pharmaceuticals in drinking water have not been not evidenced so far, these results suggest that in some areas, the population is exposed to these compounds.

IV. Conclusion

The aim of the present study was to provide baseline information and to identify patterns of pharmaceutical contamination of surface and groundwater resources in a sub-Saharan capital city according to land use, hydro-geomorphological and water use features.

The targeted compounds were suitable tracers to demonstrate that pit-latrines, landfills, the increase in built-up areas and urban planning all put heavy pressure on urban streams in Yaoundé and have an impact on water resources destined for human consumption. Both surface and groundwater were contaminated by pharmaceuticals and the levels of contamination correspond to those reported in previous studies in sub-Saharan water bodies with peak pollutions of NSAIDs and homogeneous contamination by the anti-epileptic carbamazepine. The contamination is diffuse and persistent. Groundwater is contaminated at some urban locations in particular by NSAIDs, tackling the issue of the fate of pharmaceuticals in the hydrosystem. Groundwater contamination makes populations highly vulnerable because they rely on this water supply as an alternative to a formal tap water network and to compensate for the lack of infrastructure in the capital city of Cameroon. As the city dynamics favor an increase in pressures on water resources, Yaoundé needs to adapt water uses, and public authorities need to protect water resources, the health of the inhabitants and the environment.

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References

Andreozzi, R., Marotta, R., Pinto, G., Pollio, A., 2002. Carbamazepine in water: persistence in the environment, ozonation treatment and preliminary assessment on algal toxicity. Water Res. 36, 2869–2877. https://doi.org/10.1016/S0043-1354(01)00500-0

Angbo-Effi, K.O., Kouassi, D.P., Yao, G.H.A., Douba, A., Secki, R., Kadjo, A., 2011. Facteurs déterminant la consommation des médicaments de la rue en milieu urbain, Determinants of street drug use in urban areas. Santé Publique 23, 455–464. https://doi.org/10.3917/spub.116.0455

Archundia, D., Boithias, L., Duwig, C., Morel, M.-C., Flores Aviles, G., Martins, J.M.F., 2018. Environmental fate and ecotoxicological risk of the antibiotic sulfamethoxazole across the Katari catchment (Bolivian Altiplano): Application of the GREAT-ER model. Sci. Total Environ. 622–623, 1046–1055. https://doi.org/10.1016/j.scitotenv.2017.12.026

Archundia, D., Duwig, C., Spadini, L., Uzu, G., Guédron, S., Morel, M.C., Cortez, R., Ramos Ramos, O., Chincheros, J., Martins, J.M.F., 2017. How Uncontrolled Urban Expansion Increases the Contamination of the Titicaca Lake Basin (El Alto, La Paz, Bolivia). Water. Air. Soil Pollut. 228. https://doi.org/10.1007/s11270-016-3217-0

Archundia Peralta, D., 2016. Etude du devenir et de l'impact des antibiotiques à l'échelle d'un bassin versant : application au bassin versant du Katari (Bolivie) (phdthesis). Université Grenoble Alpes.

Bachelier, G., 1959. Etude pédologique des sols de Yaoundé : contribution à l'étude de la pédologie des sols ferralitiques. ORSTOM.

Beek, T. aus der, Weber, F.-A., Bergmann, A., Hickmann, S., Ebert, I., Hein, A., Küster, A., 2016. Pharmaceuticals in the environment—Global occurrences and perspectives. Environ. Toxicol. Chem. 35, 823–835. https://doi.org/10.1002/etc.3339

Blanchoud, H., Moreau-Guigon, E., Farrugia, F., Chevreuil, M., Mouchel, J.M., 2007. Contribution

by urban and agricultural pesticide uses to water contamination at the scale of the Marne watershed. Sci. Total Environ. 375, 168–179. https://doi.org/10.1016/j.scitotenv.2006.12.009

Bon, A., Ndam Ngoupayou, J., Ewodo Mboudou, G., Ekodeck, G., 2016. Caractérisation hydrogéologique des aquifères de socle altéré et fissuré du bassin versant de l'Olézoa à Yaoundé, Cameroun. Rev. Sci. L'eau J. Water Sci. 29, 149–166. https://doi.org/10.7202/1036545ar

Branchet, P., Cadot, E., Fenet, H., Sebag, D., Ngatcha, B.N., Borrell-Estupina, V., Ngoupayou, J.R.N., Kengne, I., Braun, J.-J., Gonzalez, C., 2018. Polar pesticide contamination of an urban and peri-urban tropical watershed affected by agricultural activities (Yaoundé, Center Region, Cameroon). Environ. Sci. Pollut. Res. 1–26. https://doi.org/10.1007/s11356-018-1798-4

Bu, Q., Shi, X., Yu, G., Huang, J., Wang, B., Wang, J., 2016. Pay attention to non-wastewater emission pathways of pharmaceuticals into environments. Chemosphere 165, 515–518. https://doi.org/10.1016/j.chemosphere.2016.09.078

BUCREP, 2010. La population du Cameroun en 2010 (3ème RGPH) (Technical Report). BUCREP, Yaoundé.

Carvalho, I.T., Santos, L., 2016. Antibiotics in the aquatic environments: A review of the European scenario. Environ. Int. 94, 736–757. https://doi.org/10.1016/j.envint.2016.06.025

Carvalho, P.N., Basto, M.C.P., Almeida, C.M.R., Brix, H., 2014. A review of plant–pharmaceutical interactions: from uptake and effects in crop plants to phytoremediation in constructed wetlands. Environ. Sci. Pollut. Res. 21, 11729–11763. https://doi.org/10.1007/s11356-014-2550-3

Castiglioni, S., Davoli, E., Riva, F., Palmiotto, M., Camporini, P., Manenti, A., Zuccato, E., 2018. Mass balance of emerging contaminants in the water cycle of a highly urbanized and industrialized area of Italy. Water Res. 131, 287–298.

https://doi.org/10.1016/j.watres.2017.12.047

Commeyras, C., Ndo, J.R., Merabet, O., Kone, H., Rakotondrabe, F.P., 2006. Caractéristiques de la consommation de soins et de médicaments au Cameroun. Cah. Détudes Rech. Francoph. Santé 16, 13–19. https://doi.org/10.1684/san.2006.0002

Dauvergne, S., 2011. Les espaces urbains et péri-urbains à usage agricole dans les villes d'Afrique sub-saharienne (Yaoundé et Accra) : une approche de l'intermédiarité en géographie. Ecole Nationale Supérieure de Lyon, Lyon.

Djuikom, E., Jugnia, L.B., Nola, M., Foto, S., Sikati, V., 2009. Physicochemical water quality of the Mfoundi River watershed at Yaoundé, Cameroon, and its relevance to the distribution of bacterial indicators of faecal contamination. Water Sci. Technol. J. Int. Assoc. Water Pollut. Res. 60, 2841–2849. https://doi.org/10.2166/wst.2009.702

Djuikom, E., Njiné, T., Nola, M., Kemka, N., Togouet, S.H.Z., Jugnia, L.-B., 2008. Significance and suitability of Aeromonas hydrophila vs. fecal coliforms in assessing microbiological water quality. World J. Microbiol. Biotechnol. 24, 2665–2670. https://doi.org/10.1007/s11274-008-9793-4

Djuikom, E., Njine, T., Nola, M., Sikati, V., Jugnia, L.-B., 2006. Microbiological water quality of the Mfoundi River watershed at Yaoundé, Cameroon, as inferred from indicator bacteria of fecal contamination. Environ. Monit. Assess. 122, 171–183. https://doi.org/10.1007/s10661-005-9172-7

Dos Santos, S., Adams, E.A., Neville, G., Wada, Y., de Sherbinin, A., Mullin Bernhardt, E., Adamo, S.B., 2017. Urban growth and water access in sub-Saharan Africa: Progress, challenges, and emerging research directions. Sci. Total Environ. 607–608, 497–508. https://doi.org/10.1016/j.scitotenv.2017.06.157

Ebele, A.J., Abou-Elwafa Abdallah, M., Harrad, S., 2017. Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. Emerg. Contam. 3, 1–16.

https://doi.org/10.1016/j.emcon.2016.12.004

Echart, J., Ghebremichael, K., Khatri, K., Mutikanga, H., Sempewo, J., Tsegaye, S., Vairavamoorthy, K., 2012. The Future of Water in African Cities : Why Waste Water? Integrated Urban Water Management, Background Report (Integrated Urban Water Management, Background Report). World Bank, Washington, DC.

Epting, J., Huggenberger, P., Radny, D., Hammes, F., Hollender, J., Page, R.M., Weber, S., Bänninger, D., Auckenthaler, A., 2018. Spatiotemporal scales of river-groundwater interaction – The role of local interaction processes and regional groundwater regimes. Sci. Total Environ. 618, 1224–1243. https://doi.org/10.1016/j.scitotenv.2017.09.219

ESA, 2016. ESA CCI LAND COVER – S2 prototype Land Cover 20m map of Africa 2016 [WWW Document]. Eur. Spat. Agency. URL http://2016africalandcover20m.esrin.esa.int/ (accessed 11.10.18).

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D., Alsdorf, D., 2007. The Shuttle Radar Topography Mission. Rev. Geophys. 45. https://doi.org/10.1029/2005RG000183

Franqueville, A., 1984. Yaoundé: construire une capitale. IRD Editions.

Geest, S.V. der, 2017. Les médicaments sur un marché camerounais. Reconsidération de la commodification et de la pharmaceuticalisation de la santé. Anthropol. Santé Rev. Int. Francoph. Anthropol. Santé. https://doi.org/10.4000/anthropologiesante.2450

Gogoi, A., Mazumder, P., Tyagi, V.K., Tushara Chaminda, G.G., An, A.K., Kumar, M., 2018. Occurrence and fate of emerging contaminants in water environment: A review. Groundw. Sustain. Dev. 6, 169–180. https://doi.org/10.1016/j.gsd.2017.12.009

Gracia-Lor, E., Castiglioni, S., Bade, R., Been, F., Castrignanò, E., Covaci, A., González-Mariño, I., Hapeshi, E., Kasprzyk-Hordern, B., Kinyua, J., Lai, F.Y., Letzel, T., Lopardo, L., Meyer,

M.R., O'Brien, J., Ramin, P., Rousis, N.I., Rydevik, A., Ryu, Y., Santos, M.M., Senta, I., Thomaidis, N.S., Veloutsou, S., Yang, Z., Zuccato, E., Bijlsma, L., 2017. Measuring biomarkers in wastewater as a new source of epidemiological information: Current state and future perspectives. Environ. Int. 99, 131–150. https://doi.org/10.1016/j.envint.2016.12.016

Guetté, A., Godet, L., Robin, M., 2018. Historical anthropization of a wetland: steady encroachment by buildings and roads versus back and forth trends in demography. Appl. Geogr. 92, 41–49. https://doi.org/10.1016/j.apgeog.2018.01.012

Gwenzi, W., Chaukura, N., 2018. Organic contaminants in African aquatic systems: Current knowledge, health risks, and future research directions. Sci. Total Environ. 619–620, 1493–1514. https://doi.org/10.1016/j.scitotenv.2017.11.121

Hai, F.I., Yang, S., Asif, M.B., Sencadas, V., Shawkat, S., Sanderson-Smith, M., Gorman, J., Xu, Z.-Q., Yamamoto, K., 2018. Carbamazepine as a Possible Anthropogenic Marker in Water: Occurrences, Toxicological Effects, Regulations and Removal by Wastewater Treatment Technologies. Water 10, 107. https://doi.org/10.3390/w10020107

Hayzoun, H., Garnier, C., Durrieu, G., Lenoble, V., Le Poupon, C., Angeletti, B., Ouammou, A., Mounier, S., 2015. Organic carbon, and major and trace element dynamic and fate in a large river subjected to poorly-regulated urban and industrial pressures (Sebou River, Morocco). Sci. Total Environ. 502, 296–308. https://doi.org/10.1016/j.scitotenv.2014.09.014

He, B., Wang, J., Liu, J., Hu, X., 2017. Eco-pharmacovigilance of non-steroidal anti-inflammatory drugs: Necessity and opportunities. Chemosphere 181, 178–189. https://doi.org/10.1016/j.chemosphere.2017.04.084

INS, BGR, 2013. Etude Pilote sur la Pollution des Eaux de Surface et Souterraines à Yaoundé et son Impact sur la Santé des Populations Riveraines (EPESS) (Rapport technique). Institut National de la Statistique du Cameroun, Yaoundé (Cameroun).

Jjemba, P.K., 2008. Pharma-Ecology. John Wiley & Sons, Inc., Hoboken, NJ, USA.

https://doi.org/10.1002/9780470369340

Kenmogne, G.R.K., Rosillon, F., Mpakam, H.G., Nono, A., 2010. Enjeux sanitaires, socio-économiques et environnementaux liés à la réutilisation des eaux usées dans le maraîchage urbain : cas du bassin versant de l'Abiergué (Yaoundé-Cameroun). VertigO - Rev. Électronique En Sci. Environ. https://doi.org/10.4000/vertigo.10323

K'oreje, K.O., Vergeynst, L., Ombaka, D., De Wispelaere, P., Okoth, M., Van Langenhove, H., Demeestere, K., 2016. Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu city, Kenya. Chemosphere 149, 238–244. https://doi.org/10.1016/j.chemosphere.2016.01.095

Kotyza, J., Soudek, P., Kafka, Z., Vaněk, T., 2010. Phytoremediation of pharmaceuticals--preliminary study. Int. J. Phytoremediation 12, 306–316. https://doi.org/10.1080/15226510903563900

Kringel, R., Rechenburg, A., Kuitcha, D., Fouépé, A., Bellenberg, S., Kengne, I.M., Fomo, M.A., 2016. Mass balance of nitrogen and potassium in urban groundwater in Central Africa, Yaounde/Cameroon. Sci. Total Environ. 547, 382–395. https://doi.org/10.1016/j.scitotenv.2015.12.090

Lapworth, D.J., Das, P., Shaw, A., Mukherjee, A., Civil, W., Petersen, J.O., Gooddy, D.C., Wakefield, O., Finlayson, A., Krishan, G., Sengupta, P., MacDonald, A.M., 2018. Deep urban groundwater vulnerability in India revealed through the use of emerging organic contaminants and residence time tracers. Environ. Pollut. Barking Essex 1987 240, 938–949. https://doi.org/10.1016/j.envpol.2018.04.053

Leduc, C., Pulido-Bosch, A., Remini, B., 2017. Anthropization of groundwater resources in the Mediterranean region: processes and challenges. Hydrogeol. J. 25, 1529–1547. https://doi.org/10.1007/s10040-017-1572-6

Lieunang Letche, A.R., Fonteh, M.F., Ndam Ngoupayou, J.R., 2009. La Gestion Intégrée des

Ressources en Eau (GIRE) au Cameroun. Préoccupations environnementales affectant la gestion des ressources en eau dans le bassin versant de la Méfou., Editions universitaires européennes. ed.

Lindim, C., van Gils, J., Cousins, I.T., Kühne, R., Georgieva, D., Kutsarova, S., Mekenyan, O., 2017. Model-predicted occurrence of multiple pharmaceuticals in Swedish surface waters and their flushing to the Baltic Sea. Environ. Pollut. Barking Essex 1987 223, 595–604. https://doi.org/10.1016/j.envpol.2017.01.062

Madikizela, L.M., Tavengwa, N.T., Chimuka, L., 2017. Status of pharmaceuticals in African water bodies: Occurrence, removal and analytical methods. J. Environ. Manage. 193, 211–220. https://doi.org/10.1016/j.jenvman.2017.02.022

Matongo, S., Birungi, G., Moodley, B., Ndungu, P., 2015. Pharmaceutical residues in water and sediment of Msunduzi River, KwaZulu-Natal, South Africa. Chemosphere 134, 133–140. https://doi.org/10.1016/j.chemosphere.2015.03.093

McLachlan, P.J., Chambers, J.E., Uhlemann, S.S., Binley, A., 2017. Geophysical characterisation of the groundwater–surface water interface. Adv. Water Resour. 109, 302–319. https://doi.org/10.1016/j.advwatres.2017.09.016

Mendo, E., Boidin, B., Donfouet, H.P.P., 2015. Le recours aux micro-unités de soins informelles à Yaoundé (Cameroun) : déterminants et perspectives, Access to informal micro-care units in Yaounde (Cameroon) : determinants and prospects. J. Gest. Déconomie Médicales 33, 73–90. https://doi.org/10.3917/jgem.151.0073

Menye, D.É., Zébazé Togouet, S.H., Menbohan, S.F., Kemka, N., Nola, M., Boutin, C., Nguetsop, V.F., Djaouda, M., Njiné, T., 2012. Bio-écologie des diatomées épilithiques de la rivière Mfoundi (Yaoundé, Cameroun) : diversité, distribution spatiale et influence des pollutions organiques. Rev. Sci. Eau 25, 203. https://doi.org/10.7202/1013103ar

Misson, B., Garnier, C., Lauga, B., Dang, D.H., Ghiglione, J.-F., Mullot, J.-U., Duran, R., Pringault,

O., 2016. Chemical multi-contamination drives benthic prokaryotic diversity in the anthropized Toulon Bay. Sci. Total Environ. 556, 319–329. https://doi.org/10.1016/j.scitotenv.2016.02.038

Moffo, M.O.Z., Tsalefac, M., Iaţu, C., 2011. Floods risks in the Mfoundi upstream drainage basin in Yaoundé: a response to climatic modifications or to human impacts? Present Environ. Sustain. Dev. 5.

Moffo, M.O.Z., Tsalefac, M., Ursu, A., Iatu, C., 2016. Contribution of Geographic Information Systems for the Mapping of Flooding Factors in Yaoundé: The Case Study of Mfoundi Upstream Watershed. Present Environ. Sustain. Dev. 10, 217–234. https://doi.org/10.1515/pesd-2016-0019

Mompelat, S., Le Bot, B., Thomas, O., 2009. Occurrence and fate of pharmaceutical products and by-products, from resource to drinking water. Environ. Int., Pharmaceutical products in the environment: trends toward lowering presence and impact 35, 803–814. https://doi.org/10.1016/j.envint.2008.10.008

Mottes, C., Lesueur-Jannoyer, M., Charlier, J.-B., Carles, C., Guéné, M., Le Bail, M., Malézieux, E., 2015. Hydrological and pesticide transfer modeling in a tropical volcanic watershed with the WATPPASS model. J. Hydrol. 529, Part 3, 909–927. https://doi.org/10.1016/j.jhydrol.2015.09.007

Naah, M., 2013. Impact temporel du développement urbain du bassin versant de la Mingoa sur la qualité du lac municipal de Yaoundé (Cameroun). Université Paris-Est, Ecole des Ponts Paris Tech.

Ntep, F., Kengne, I.M., Mboudou, G.E., Nyochembeng, N., Ekodeck, E., 2014. Influence of seasonal dynamics on groundwater resources quality in semitropical urban zone: case of the Biyémé upper stream catchment (Yaounde, Cameroon). Int. J. Biol. Chem. Sci. 8, 1319–1335. https://doi.org/10.4314/ijbcs.v8i3.44

Olatunde, J.O., Chimezie, A., Tolulope, B., Aminat, T.T., 2014. Determination of pharmaceutical compounds in surface and underground water by solid phase extraction-liquid chromatography. J. Environ. Chem. Ecotoxicol. 6, 20–26. https://doi.org/10.5897/JECE2013.0312

Olivry, J.-C., 1986. Fleuves et rivières du Cameroun, Monographies hydrologiques. MESRES-ORSTOM, Bondy.

OMS, ONU-Habitat, 2010. La Face cachée des villes : Mettre au jour et vaincre les inégaliés en santé en milieu urbain. OMS.

OpenStreetMap Contributors, 2018. OpenStreetMap [WWW Document]. OpenStreetMap. URL https://www.openstreetmap.org/ (accessed 11.10.18).

Peake, B.M., Braund, R., Tong, A., Tremblay, L.A., 2015. The Life-Cycle of Pharmaceuticals in the Environment. Elsevier.

Pongmala, K., Autixier, L., Madoux-Humery, A.-S., Fuamba, M., Galarneau, M., Sauvé, S., Prévost, M., Dorner, S., 2015. Modelling total suspended solids, E. coli and carbamazepine, a tracer of wastewater contamination from combined sewer overflows. J. Hydrol. 531, 830–839. https://doi.org/10.1016/j.jhydrol.2015.10.042

Schaider, L.A., Ackerman, J.M., Rudel, R.A., 2016. Septic systems as sources of organic wastewater compounds in domestic drinking water wells in a shallow sand and gravel aquifer. Sci. Total Environ. 547, 470–481. https://doi.org/10.1016/j.scitotenv.2015.12.081

Srang, K., 1972. Hydrologie d'un bassin de zone urbaine. Le bassin versant de Yaoundé. (Mémoire de stage). Office de la Recherche Scientifique et Technique Outre-Mer.

Tabué Youmbi, J.G., Ntamack, D., Feumba, R., Ngnikam, E., Wéthé, J., Tanawa, É., 2009. Vulnérabilité des eaux souterraines et périmètres de protection dans le bassin versant de la Mingoa (Yaoundé, Cameroun). Rev. L'Université Monct. 40, 71. https://doi.org/10.7202/1001389ar

Takounjou, A.F., Rao, V., Ngoupayou, J.N., Nkamdjou, L.S., Ekodeck, G.E., 2009. Groundwater flow modelling in the upper Anga'a river watershed, Yaounde, Cameroon. Afr. J. Environ. Sci. Technol. 3.

Tanawa, E., Tchapnga, H.B.D., Ngnikam, E., Temgoua, E., Siakeu, J., 2002. Habitat and protection of water resources in suburban areas in African cities. Build. Environ. 37, 269–275. https://doi.org/10.1016/S0360-1323(01)00024-5

Tchotsoua, M., 1994. Dynamique informelle de l'espace urbain et érosion accélérée en milieu tropical humide : le cas de la ville de Yaoundé. Cah. O.-m. 47, 123–136. https://doi.org/10.3406/caoum.1994.3508

Thiebault, T., Boussafir, M., Le Milbeau, C., 2017. Occurrence and removal efficiency of pharmaceuticals in an urban wastewater treatment plant: Mass balance, fate and consumption assessment. J. Environ. Chem. Eng. 5, 2894–2902. https://doi.org/10.1016/j.jece.2017.05.039

Vu, H.M., Shanafield, M., Batelaan, O., 2018. Flux dynamics at the groundwater-surface water interface in a tropical catchment. Limnologica, Special Issue on Aquatic interfaces and linkages: An emerging topic of interdisciplinary research 68, 36–45. https://doi.org/10.1016/j.limno.2017.06.003

Wethé, J., Radoux, M., Tanawa, E., 2003. Assainissement des eaux usées et risques socio – sanitaires et environnementaux en zones d'habitat planifié de Yaoundé (Cameroun). VertigO - Rev. Électronique En Sci. Environ. https://doi.org/10.4000/vertigo.4741

Whitehead, M., Dahlgren, G., 1991. What can be done about inequalities in health? The Lancet 338, 1059–1063. https://doi.org/10.1016/0140-6736(91)91911-D

WHO, 2008. Advocacy, communication and social mobilization for TB control: a guide to developing knowledge, attitude and practice surveys. World Health Organization : Stop TB Partnership, Geneva.

Wilkinson, J., Hooda, P.S., Barker, J., Barton, S., Swinden, J., 2017. Occurrence, fate and transformation of emerging contaminants in water: An overarching review of the field. Environ. Pollut. 231, 954–970. https://doi.org/10.1016/j.envpol.2017.08.032

Williams, R.J., Keller, V.D.J., Johnson, A.C., Young, A.R., Holmes, M.G.R., Wells, C., Gross-Sorokin, M., Benstead, R., 2009. A national risk assessment for intersex in fish arising from steroid estrogens. Environ. Toxicol. Chem. 28, 220–230. https://doi.org/10.1897/08-047.1

Youmbi, J.G.T., Feumba, R., Njitat, V.T., Marsily, G. de, Ekodeck, G.E., 2013. Pollution de l'eau souterraine et risques sanitaires à Yaoundé au Cameroun. C. R. Biol. 336, 310–316. http://dx.doi.org/10.1016/j.crvi.2013.04.013

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