A Focus on Active Chemicals in Sub-Saharan Africa

Subjects: Environmental Sciences
Contributor: ASHA RIPANDA

Active chemicals are among the contaminants of emerging concern that are rarely covered in regulatory documents in sub-Saharan Africa.

Keywords: Active chemicals (ACs) ; Pharmaceutical load ; Sub-Saharan Africa (SSA) ; Environmental Toxicology ; Drug-drug interactions ; Wastewater ; Mixture ; Contaminants

1. Environmental Effects of Active Chemicals

The existence of different categories of active chemicals in the environmental matrices has been reported in some sub-Saharan African countries. These reports indicate the presence of the active chemicals, and point to a possibility of the ACs causing harm not only to human health but also to the natural environment. Most drugs reported were anti-inflammatories, antibiotics, antiretroviral drugs, analgesics, psychiatric treatment drugs, steroid hormones, diabetes treatment drugs, or hypertension drugs. Loads of active chemicals released into the environment after human, animal, and agricultural usage have been linked to both human and environmental health degradation. Although active chemicals are considered to be contaminants of emerging concern, they are currently neither monitored nor included in the environmental guidelines.

Chemicals that are environmentally persistent and have a tendency to bioaccumulate pose a great potential for environmental risk, especially when such chemicals come into contact with drinking water supplies and the food chain [1][2][3]. Various scholars have reported the effects of these substances and their potential for harm, including the development of AMR [4][5][6][7], as well as effects on the sex of aquatic organisms [8][9][10][11][12][13][14]. The early years of research in the area of the effects of ACs placed more emphasis on the assessment of the acute effects as a result of individual substances, largely ignoring the effects that may be caused by combinations of these substances. Recently, however, there has been a shift in focus to chronic exposure and the assessment of the effects of drug mixtures [12][14][15][16]. It is important to study drug mixtures—commonly described as a ‘cocktail effect’—including drug-drug interactions leading to adverse effects. Usually, human subjects receive a prescription with instructions on how to properly use drug mixtures. For instance, patients should not mix ibuprofen with beta-blockers, or opioids with alcohol. However, other organisms in the ecosystem do not receive instructions from medical doctors. As a result, a fish reeling in an effluent containing a mixture of drugs and other contaminants in a polluted river will simply succumb to the adverse effects thereof.

2. Environmental Load of Active Chemicals

Active chemicals are now some of the main environmental pollutants and are abundant in water, soils, and other environmental media. Environmental risk assessment and routine environmental monitoring regulations do not include active chemicals, simply because acute risk assessments show insignificant human health hazards. However, the drawbacks of active chemicals extend beyond acute effects to delayed effects from bioaccumulation, amplified effects from drug-drug interactions, aggravation of drug resistance, and reduction in aquatic and terrestrial food production; this merits serious measures for public health protection [17]. Reports on the presence of active chemicals in the sub-Saharan African environment are still scarce, with only a few countries reporting [18][19], indicating a need for more research. Therefore, this review will aid in providing data that are necessary to indicate the presence and possible harm of active chemicals in the sub-Saharan African environment, and to inform current and future policymaking processes.

Occurrences of Active Chemicals in Other Parts of Africa

Apart from sub-Saharan African countries, South Africa is among the African countries with greater awareness and practice concerning environmental protection [18][20][21][22][23]. In most developed countries, the use of active chemicals is higher; thus, the load to the environment may also be higher. Occurrences of active chemicals in the South African environmental compartments are presented in **Table 1**. Additionally, research [24], has reported that pollutants arise not only from waste products but also from pharmaceutical products that have not been properly disposed of. The continuous exposure to unspecified sub-therapeutic doses of antibiotics presents a risk to humans and other animals.

Table 1. Occurrences of ACs in the South African environmental compartments.

Matrix	Substance (s)	Concentration (ng/L)	References
Wastewater	Clarithromycin	5–30	[23]
	Erythromycin	10–100	
	Sulfadimidine	0–10	
	Sulfamethoxazole	5–1000	
	Sulfapyridine	5–110	
	Chlortetracycline	90	
	Oxytetracycline	100	
	Trimethoprim	5–10,000	
Seawater	Ibuprofen	160	[20]
	Naproxen	160	
Wastewater	Nevirapine and efavirenz	2100 ng/L 17,400 ng/L	[25]
Wastewater	Ibuprofen	117,000	[26]
Surface water		84,600	
Sediments		65,900	
Water	Concentrations were efavirenz > nevirapine > carbamazepine > methocarbamol > bromacil > venlafaxine.	164–593	[27]
Surface water	Antiretrovirals (ARVs)	26.5–430	[28]

3. Active Chemicals in the Sub-Saharan African Context

Information on the occurrence of quantifiable levels of active chemicals in the sub-Saharan African environment is lacking. It is known that therapeutic consumption of active chemicals to promote human health is usually followed by excretion of these drugs via urine or fecal matter, due to their slight alteration of the human metabolism. The detection of several active chemical classes—including nonsteroidal anti-inflammatories, antibiotics, antiretrovirals, anti-epileptics, steroid hormones, and anti-malarial drugs—has been reported in water resources, influents, and effluents in some countries in sub-Saharan Africa [18][20][29][30]. Moreover, general investigation and monitoring of active chemicals in different sub-Saharan African countries are required, and the necessary instrumentation for their trace quantification in environmental samples should be made available.

3.1. Kenya

Reports of the presence of active chemicals in the Kenyan environment are available [31][32][33]. Some exclusive data on the concentrations and loads of chemicals such as antibiotics, antivirals, analgesics, anti-inflammatories, and psychiatric drugs are presented in **Table 2**.

Table 2. Occurrences of ACs in the Kenyan environmental compartments.

Substances	Effluents	Surface Water (ng/L)	Sediments (ng/Kg)	References
Norfloxacin	4.2	1.6 to 4.9	248 to 776	[33]
Trimethoprim	15.8	3.8 to 4.4	11 to 90	
Ciprofloxacin	5.3	2.5 to 2.8	4125 to 1225	
Sulfamethoxazole	956.4	96.9 to 142.6	542 to 896	
Lamivudine	847.1	219.6 to 228.3	107 to 491	
Zidovudine	1.4	1.1 to 21	118 to 510	
Clavulanic acid	10–110			[23]
Erythromycin	100–150			
Sulfadimidine	0–5			
Sulfamerazine	2–20			
Minocycline	0			
Tetracycline	10–180			
Trimethoprim	5–100			
Lincomycin	5–80			

3.2. Uganda

The presence of quantifiable levels of active chemicals was investigated in Uganda's environmental compartments [34][35][36]. The results indicate the presence of active chemicals belonging to multiple therapeutic categories, as presented in **Table 3**.

Table 3. Occurrences of ACs in the Ugandan environmental compartments.

Matrix	Substance	Concentration (ng/ L)	References
Lake Victoria water	Sulfamethoxazole	1–5600	[35]
	Trimethoprim	1–89 L	
	Tetracycline	3–70	
	Sulfacetamide	1–13	
	Erythromycin	10–66	
	Sulfamethazine	2–50	
	Carbamazepine	5–72	
	Ibuprofen	6–780	
	Diclofenac	2–160	
	Sulfamethoxazole	1–5600	

3.3. Tanzania

In Tanzania, as in other sub-Saharan countries, wastewater treatment plants are not designed for the removal of emerging contaminants such as active chemicals. Wastewater stabilization ponds are utilized to partially treat the effluents from industries, residential areas, and hospitals. Therefore, when effluents are released into the ecosystem, the chemical load is increased [37][38][39][40][41][42][43]. Occurrences of the active chemicals in the Tanzanian environment are presented in **Table 4.**

Table 4. Occurrences of ACs in the Tanzanian environmental compartments.

Matrix	Substance	Concentration	References
Wastewater	Metronidazole	0.065–0.104 ppm	[40]
Msimbazi River waters	Metronidazole	0.0024 ppm	[42]
	Paracetamol	0.0060 ppm	
	Cetirizine	0.0073 ppm	
	Ibuprofen	0.0016 ppm	
Wastewater effluents	Ampicillin	bdl to 0.367 ppm	[37]
	Ciprofloxacin	bdl to 0.037 ppm	
AMR Lake Victoria water	Sulfamethoxazole/trimethoprim	100%	[41]
	Ampicillin/cloxacillin	100%	
	Erythromycin	72.7%	
	Tetracycline	90.9%	
	Nalidixic acid	63.6%	

3.4. Zambia

According to the available information, Zambia's environmental compartments were mostly affected by the presence of active chemicals from the classes of antibiotics and antivirals, as presented in **Table 5**. Although the industrial release of these contaminants is possible, a report indicated only the presence of metalloid toxicants [44]. As there were only a few studies, there is a need to further investigate the presence of active chemicals and other emerging contaminants in the Zambian environment.

Table 5. Occurrences of ACs in the Zambian environmental matrices.

Matrix	Substance	Concentration	References
Urine	Sulfamethoxazole	7740 μg/L	[45]
	Trimethoprim	12,800 μg/L	
	Lamivudine	10,010 μg/L	
Surface water	Antibiotics	11,800 ng/L	
	Antivirals	49,700 ng/L	
Effluents	Antibiotics	100–300,400 ng/L	
	Antivirals	680–55,760 ng/L	

References

1. Abelkop, A.D.; Graham, J.D.; Royer, T.V. Persistent, Bioaccumulative, and Toxic (PBT) Chemicals: Technical Aspects, Policies, and Practices, 1st ed.; CRC Press: Boca Raton, FL, USA, 2018.
2. Zhang, W.; Asiri, A.M.; Liu, D.; Du, D.; Lin, Y. Nanomaterial-based biosensors for environmental and biological monitoring of organophosphorus pesticides and nerve agents. TrAC Trends Anal. Chem. 2014, 54, 1–10.
3. Pandey, S.; Goswami, G.K.; Okoro, H.K.; Fosso-Kankeu, E. Carbon nanotubes in the 21st Century: An Advancement in real time monitoring and control of environmental water. In Nano and Bio-Based Technologies for Wastewater; Scrivener Publishing LLC: Beverly, UK, 2019; pp. 265–301.
4. Prestinaci, F.; Pezzotti, P.; Pantosti, A. Antimicrobial resistance: A global multifaceted phenomenon. Pathog. Glob. Health 2015, 108, 309–318.
5. Michael, C.A.; Dominey-Howes, D.; Labbate, M. The antimicrobial resistance crisis: Causes, consequences, and management. Front. Public Health 2014, 2, 1–8.
6. Jansen, K.U.; Anderson, A.S. The role of vaccines in fighting antimicrobial resistance (AMR). Hum. Vaccines Immunother. 2018, 14, 2142–2149.

7. Miraji, H.; Othman, O.C.; Ngassapa, F.; Eunice, M. Analytical perspectives on emerging organic contaminants in the aquatic ecosystem. In Effects of Emerging Chemical Contaminants on Water Resources and Environmental Health; IGI Global: Hershey, PA, USA, 2020; pp. 68–80.

8. Jarque, S.; Quirós, L.; Grimalt, J.O.; Gallego, E.; Catalan, J.; Lackner, R.; Piña, B. Background fish feminization effects in European remote sites. Sci. Rep. 2015, 5, 11292.

9. García-Berthou, E.; Bae, M.-J.; Benejam, L.; Alcaraz, C.; Casals, F.; de Sostoa, A.; Solà, C.; Munné, A. Fish-based indices in Catalan rivers: Intercalibration and comparison of approaches. In Experiences from Surface Water Quality Monitoring; Springer: Berlin/Heidelberg, Germany, 2015; pp. 125–147.

10. Hamilton, P.B.; Nicol, E.; De-Bastos, E.S.R.; Williams, R.J.; Sumpter, J.P.; Jobling, S.; Stevens, J.R.; Tyler, C.R. Populations of a cyprinid fish are self-sustaining despite widespread feminization of males. BMC Biol. 2014, 12, 1.

11. Pérez, M.R.; Fernandino, J.I.; Carriquiriborde, P.; Somoza, G.M. Feminization and altered gonadal gene expression profile by ethinylestradiol exposure to pejerrey, Odontesthes bonariensis, a South American teleost fish. Environ. Toxicol. Chem. Lat. Am. 2012, 31, 941–946.

12. Sanchez, W.; Sremski, W.; Piccini, B.; Palluel, O.; Maillot-Marechal, E.; Betoulle, S.; Jaffal, A.; Aït-Aïssa, S.; Brion, F.; Thybaud, E.; et al. Adverse effects in wild fish living downstream from pharmaceutical manufacture discharges. Environ. Int. 2011, 37, 1342–1348.

13. Tyler, C.R.; Jobling, S. Roach, Sex, and Gender-Bending Chemicals: The Feminization of Wild Fish in English Rivers. BioScience 2008, 58, 1051–1059.

14. Richards, S.M.; Wilson, C.J.; Johnson, D.J.; Castle, D.M.; Lam, M.; Mabury, S.A.; Sibley, P.K.; Solomon, K.R. Effects of pharmaceutical mixtures in aquatic microsms. Environ. Toxicol. Chem. 2004, 23, 1035–1042.

15. Vasquez, M.I.; Lambrianides, A.; Schneider, M.; Kümmerer, K.; Fatta-Kassinos, D. Environmental side effects of pharmaceutical cocktails: What we know and what we should know. J. Hazard. Mater. 2014, 279, 169–189.

16. Michael, I.; Vasquez, M.I.; Hapeshi, E.; Haddad, T.; Baginska, E.; Kümmerer, K.; Fatta-Kassinos, D. Metabolites and Transformation Products of Pharmaceuticals in the Aquatic Environment as Contaminants of Emerging Concern; Wiley, John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2014; pp. 413–459.

17. Kamba, P.F.; Kaggwa, B.; Munanura, E.I.; Okurut, T.; Kitutu, F.E. Why regulatory indifference towards pharmaceutical pollution of the environment could be a missed opportunity in public health protection. a holistic view. Pan Afr. Med. J. 2017, 27, 4.

18. Madikizela, L.M.; Tavengwa, N.T.; Chimuka, L. Luke Chimuka Status of pharmaceuticals in African water bodies: Occurrence, removal and analytical methods. Environ. Manag. 2017, 193, 211–230.

19. Atnafie, S.A.; Muluneh, N.Y.; Getahun, K.A.; Tsegaw Woredekal, A.; Kahaliw, W. Pesticide Residue Analysis of Khat Leaves and Health Risks among Khat Chewers in the Amhara Region, Northwestern Ethiopia. J. Environ. Public Health 2021, 2021, 4680573.

20. Ngubane, N.P.; Naicker, D.; Ncube, S.; Chimuka, L.; Madikizela, L.M. Determination of naproxen, diclofenac and ibuprofen in Umgeni estuary and seawater: A case of northern Durban in KwaZulu-Natal Province of South Africa. Reg. Stud. Mar. Sci. 2019, 29, 100675.

21. Oyedemi, S.; Oyedemi, B.; Coopoosamy, R.; Prieto, J.; Stapleton, P.; Gibbons, S. Antibacterial and norfloxacin potentiation activities of Ocimum americanum L. against methicillin resistant Staphylococcus aureus. S. Afr. J. Bot. 2017, 109, 308–314.

22. Lorenzo, M.; Campo, J.; Suárez-Varela, M.M.; Picó, Y. Occurrence, distribution and behavior of emerging persistent organic pollutants (POPs) in a Mediterranean wetland protected area. Sci. Total Environ. 2019, 646, 1009–1020.

23. Segura, P.A.; Takada, H.; Correa, J.A.; El Saadi, K.; Koike, T.; Onwona-Agyeman, S.; Ofosu-Anim, J.; Sabif, E.B.; Wasongag, O.V.; Mghalu, J.M.; et al. Global occurrence of anti-infectives in contaminated surface waters: Impact of income inequality between countries. Environ. Int. 2015, 80, 89–97.

24. Ngqwala, N.P.; Muchesa, P. Occurrence of pharmaceuticals in aquatic environments: A review and potential impacts in South Africa. S. Afr. J. Sci. 2020, 116, 1–7.

25. Schoeman, C.; Mashiane, M.; Dlamini, M.; Okonkwo, O. Quantification of selected antiretroviral drugs in a wastewater treatment works in South Africa using GC-TOFMS. J. Chromatogr. Sep. Tech. 2015, 6, 1–7.

26. Matongo, S.; Birungi, G.; Moodley, B.; Ndungu, P. Pharmaceutical residues in water and sediment of Msunduzi River, kwazulu-natal, South Africa. Chemosphere 2015, 134, 133–140.

27. Rimayi, C.; Chimuka, L.; Gravell, A.; Fones, G.R.; Mills, G.A. Use of the Chemcatcher® passive sampler and time-of-flightmass spectrometry to screen for emerging pollutants in rivers in Gauteng Province of South Africa. Environ. Monit.

Assess 2019, 2019, 388.

28. Wood, T.P.; Duvenage, C.S.; Rohwer, E. The occurrence of anti-retroviral compounds used for HIV treatment in South African surface water. J. Environ. Pollut. 2015, 199, 235–243.

29. Madikizela, L.M.; Ncube, S.; Chimuka, L. Luke Chimuka Analysis, occurrence and removal of pharmaceuticals in African water resources: A current status. Environ. Manag. 2020, 253, 109741.

30. Lapworth, D.J.; Nkhuwa, D.C.W.; Okotto-Okotto, J.; Pedley, S.; Stuart, M.E.; Tijani, M.N.; Wright, J.J.H.J. Urban groundwater quality in sub-Saharan Africa: Current status and implications for water security and public health. Hydrogeol. J. 2017, 25, 1093–1116.

31. Muriuki, C.W.; Home, P.G.; Raude, J.M.; Ngumba, E.K.; Munala, G.K.; Kairigo, P.K.; Gachanja, A.N.; Tuhkanen, T.A. Occurrence, distribution, and risk assessment of pharmerciuticals in wastewater and open surface drains of peri-urban areas: Case study of Juja town, Kenya. Environ. Pollut. 2020, 267, 115503.

32. K'oreje, K.O.; Kandie, F.J.; Vergeynst, L.; Abira, M.A.; Van Langenhove, H.; Okoth, M.; Demeestere, K. Occurrence, fate and removal of pharmaceuticals, personal care products and pesticides in wastewater stabilization ponds and receiving rivers in the Nzoia Basin, Kenya. Sci. Total Environ. 2018, 637, 336–348.

33. Kairigo, P.; Ngumba, E.; Sundberg, L.-R.; Gachanja, A.; Tuhkanen, T. Contamination of Surface Water and River Sediments by Antibiotic and Antiretroviral Drug Cocktails in Low and Middle-Income Countries: Occurrence, Risk and Mitigation Strategies. Water 2020, 12, 1376.

34. Ekane, N.; Mertz, C.K.; Slovic, P.; Kjellén, M.; Westlund, H. Risk and benefit judgment of excreta as fertilizer in agriculture: An exploratory investigation in Rwanda and Uganda. Hum. Ecol. Risk Assess. 2015, 2015, 639–666.

35. Nantaba, F.; Wasswa, J.; Kylin, H.; Palm, W.-U.; Bouwman, H.; Kümmerer, K. Occurrence, distribution, and ecotoxicological risk assessment of selected pharmaceutical compounds in water from Lake Victoria, Uganda. Chemosphere 2020, 239, 124642.

36. Dalahmeh, S.; Tirgani, S.; Komakech, A.J.; Niwagaba, C.B.; Ahrens, L. Per- and polyfluoroalkyl substances (PFASs) in water, soil and plants in wetlands and agricultural areas in Kampala, Uganda. Sci. Total Environ. 2018, 631, 660–667.

37. Kihampa, C. β-lactams and Fluoroquinolone Antibiotics in influents and effluents of Wastewater treatment plants, Dar es Salaam, Tanzania. Res. J. Chem. Sci. 2014, 2231, 606.

38. Kaseva, M.E.; Mwegoha, W.J.S.; Kihampa, C.; Matiko, S. Performance of a waste stabilization pond system treating domestic and hospital wastewater and its implications to the aquatic environment-a case study in Dar es Salaam, Tanzania. J. Build. Land Dev. 2008, 15, 14.

39. Mhongole, O.J.; Mdegela, R.H.; Kusiluka, L.J.M.; Forslund, A.; Dalsgaard, A. Characterization of Salmonella spp. from wastewater used for food production in Morogoro, Tanzania. World J. Microbiol. Biotechnol. 2017, 33, 42.

40. Makokola, S.K.; Ripanda, A.; Miraji, H. Quantitative Investigation of Potential Contaminants of Emerging Concern in Dodoma City: A Focus at Swaswa Wastewater Stabilization Ponds. Egypt. J. Chem. 2019, 63, 427–436.

41. Baniga, Z.; Hounmanou, Y.M.G.; Kudirkiene, E.; Kusiluka, L.J.M.; Mdegela, R.H.; Dalsgaard, A. Genome-Based Analysis of Extended-Spectrum β-Lactamase-Producing Escherichia coli in the Aquatic Environment and Nile Perch (Lates niloticus) of Lake Victoria, Tanzania. Front. Microbiol. 2020, 11, 108.

42. Hossein, M.; Chande, O.; Faustin, N.; Erwin, M. Spatial Occurrence and Fate Assessment of Potential Emerging Contaminants in the Flowing Surface Waters. Chem. Sci. Int. J. 2018, 24, 1–11.

43. Outwater, A.H.; Pamba, S.; Outwater, A.B. Water-Related Diseases of People Using Municipal Wastewater: Risks, Exposure, Effects on Health and Control Approaches in Tanzania; VLIR-UOS: Da res Salaam, Tanzania, 2013; Volume 132, p. 133.

44. Ettler, V.; Mihaljevic, M.; Kříbek, B.; Majer, V.; Šebek, O. Tracing the spatial distribution and mobility of metal/metalloid contaminants in Oxisols in the vicinity of the Nkana copper smelter, Copperbelt province, Zambia. Geoderma 2011, 164, 73–84.

45. Ngumba, E.; Gachanja, A.; Nyirenda, J.; Maldonado, J.; Tuhkanen, T. Occurrence of antibiotics and antiretroviral drugs in source-separated urine, groundwater, surface water and wastewater in the peri-urban area of Chunga in Lusaka, Zambia. Water SA 2020, 46, 278–284.