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Pharmaceutical Residues in Sewage Sludge from Jordan's Largest Wastewater Treatment Plant: Implications for Sustainable Biosolids Management and Circular Economy

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Abstract

Sewage sludge is increasingly recognized as both a valuable resource and a potential source of emerging contaminants within circular economy frameworks. In Jordan, expanding wastewater treatment infrastructure has resulted in the generation of substantial quantities of sewage sludge requiring sustainable management and safe reuse strategies. As-Samra Wastewater Treatment Plant (WWTP) is the largest wastewater treatment facility in Jordan which treats approximately 125 million m^3 per year of municipal wastewater and produces around 54,001 tons of dry sludge per year. While biosolids generated from wastewater treatment offer significant opportunities for resource recovery and agricultural reuse, however, it is still that the occurrence of pharmaceutical residues may present environmental and public health challenges that require further investigation and monitoring. This study assessed the occurrence and distribution of selected pharmaceutical compounds in wastewater and sewage sludge collected from As-Samra WWTP. Influent wastewater, treated effluent, and sludge samples were analyzed using liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS). Target compounds included antibiotics, anti-inflammatory drugs, antiepileptics, and antimicrobial agents. Eight pharmaceutical compounds were detected, including carbamazepine, ciprofloxacin, flumequine, lincomycin, ofloxacin, pyrimethamine, sulfapyridine, and diclofenac. Influent concentrations ranged from 243 to 4,784 ng/L, while removal efficiencies varied between 39% and 100%. Ciprofloxacin and lincomycin were completely removed from the aqueous phase, whereas carbamazepine exhibited the lowest removal efficiency (39%), confirming its persistence during conventional wastewater treatment processes. Pharmaceutical residues were also detected in sewage sludge which is demonstrating that sorption to solids represents an important removal pathway during wastewater treatment. For example, Ciprofloxacin (289 ng/g), carbamazepine (181 ng/g), and ofloxacin (110 ng/g) exhibited the highest sludge concentrations, while diclofenac, sulfapyridine, pyrimethamine, and flumequine were detected at lower levels. The accumulation of these compounds in sludge highlights the importance of incorporating emerging contaminants into sludge quality assessments prior to land application or beneficial reuse. Building upon recent national-scale investigations of pharmaceutical residues in sewage sludge from Jordanian wastewater treatment plants, the findings contribute to understanding the environmental fate of pharmaceuticals in wastewater treatment systems. In Jordan, the quality of wastewater sludge (biosolids) is regulated under the Jordanian Standard JS 1145/2016, which classifies treated sludge into three categories based on heavy metal concentrations, pathogen levels, and moisture content for different reuse and disposal applications. However,

the current standard does not include regulatory limits for pharmaceutical residues and other emerging contaminants. Therefore, the generated data can support future updates of sludge quality regulations and the development of risk-based assessment frameworks for sustainable biosolids reuse, resource recovery, and circular economy applications in Jordan. The findings ultimately support the development of sustainable sludge management strategies that maximize resource recovery while ensuring environmental protection and safe biosolids utilization in Jordan and other water-scarce regions.

Keywords: sewage sludge, pharmaceuticals, circular economy, wastewater treatment, resource recovery, Jordan

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