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Assessing the Efficacy of Commercial Activated Carbon Adsorption in Removing Emerging Contaminants from Wastewater

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Abstract. Powdered activated carbon was used in different studies for evaluation in micropollutants removal. In this study, powdered activated carbon was tested to evaluate its removal efficiency for about 46 micropollutants. A total of 33 compounds were found in raw wastewater. The PAC was found to be efficient towards total suspended solids elimination. Powdered activated carbon reached high removal percentage for heavy metals (90%), while the majority of the other compounds it varied between 60 and 80%. The impact of advanced treatments combination with conventional treatments could lead to high removals.

1 Introduction

Wastewater treatment plants (WWTPs) stand as critical gatekeepers in the effort to protect our aquatic ecosystems from the onslaught of urban pollution. By serving as a crucial transition point between the urban wastewater collection systems and the natural aquatic environments, these facilities are tasked with mitigating the adverse impacts of micropollutants (MPs) on water bodies. These MPs, ranging from pharmaceuticals to personal care products, pose significant threats to aquatic life and potentially human health due to their persistence and bioaccumulation tendencies [1-5].

Recent research has shed light on the pressing issue of MPs in urban wastewater, prompting an in-depth examination of their concentrations and pathways through conventional WWTPs. The literature underscores a concerted effort spanning over two decades, focusing on various treatment processes—such as adsorption, nanofiltration, and

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ozonation—aimed at curbing the release of MPs into the environment. These methodologies have been scrutinized for their effectiveness in addressing the complex chemical and physical properties characteristic of wastewater, with advanced treatment technologies emerging as a pivotal strategy in this ongoing battle [6-32].

The drive towards incorporating advanced treatment methods into WWTPs reflects a multifaceted approach to pollution control, emphasizing not only the enhancement of existing systems but also the reduction of pollutants at the source. However, the adoption of such innovative solutions has been uneven globally, with regions like Morocco lagging in the implementation of these cutting-edge technologies. This gap underscores a vital area for development, given the proven efficacy of advanced treatments in achieving removal efficiencies upwards of 75% for MPs [15, 19, 24, 27, 33-49].

In light of these challenges, our study zeroes in on the conventional wastewater treatment facility in Al-Hoceima, a pivotal city nestled along Morocco's northern coastline. This region, straddling the central Rif and bordered by the Mediterranean Sea, provides a unique backdrop for investigating the dynamics of wastewater treatment in a coastal urban setting. The selection of Al-Hoceima's WWTP for this study is strategic, offering insights into the operational realities of managing wastewater in a city that bridges the western and eastern Rif regions.

Our research monitored 46 distinct MPs at the Al-Hoceima WWTP, with a special focus on evaluating the effectiveness of activated carbon in purging these pollutants from the wastewater. Through a series of three experimental trials, we aimed to unravel the potential of activated carbon adsorption as an advanced treatment strategy. This endeavor sought to illuminate whether integrating such a process could significantly enhance the plant's efficiency in eliminating the targeted MPs.

The implications of this study extend beyond the immediate context of Al-Hoceima, offering valuable lessons for WWTPs worldwide. By dissecting the performance of an advanced treatment step within a conventional wastewater treatment framework, we aim to contribute to the global discourse on sustainable water management practices. Our findings promise to offer a clearer understanding of the technological, operational, and environmental considerations critical to advancing wastewater treatment and safeguarding our aquatic ecosystems for future generations.

2 Materials and methods

2.1.Presentation of the wastewater treatment plant of Al-Hoceima city

The Al-Hoceima wastewater treatment plant processes up to 9,600 cubic meters of wastewater daily through a series of stages designed for optimal pollutant removal. The initial phase involves preliminary treatment steps like screening and grit removal to prepare the water for further processing. The core of the treatment is an advanced activated sludge system, equipped for extended aeration, which efficiently reduces carbon and nitrogen content at a loading rate under 0.32 kg BOD5/ (m3.d) [45, 46].

This system includes a biological reactor divided into an aerobic zone for bacterial metabolism and an anoxic zone making up 20% of the reactor, positioned upstream for enhanced purification. The process concludes with tertiary treatment—micro-screening and UV disinfection—to eliminate remaining particles and pathogens, ensuring the effluent's safety for release into the environment.

2.2. Characteristics of activated carbon

Activated carbon is available in two varieties: powdered (PAC) and granular (GAC). PAC's form enables it to be directly added to clarifiers and mixing tanks. In these experiments, the PAC variant utilized was named X, sourced from various manufacturers. Table 1 presents the physical characteristics of the tested activated carbon. A critical factor in micropollutant removal is the size of the particles. Through laser diffraction analysis, insights into the particle size were obtained, with the results detailed in Table 1.

Table 1. Characteristics of the tested PAC (X).

Properties	**X**
Precursor material	Peat
Pore volume (cm3/g)	0.5
Skeletal density (g/cm3)	2.3
Distribution of particle size (µm)	
D90	98
D50	25
D10	3

2.3. Sampling campaigns and description of the pilot plant reactor (Lab-scale)

From January to March, three sampling campaigns were conducted, during which 20-liter composite samples of pretreated effluent were collected over 24 hours using automatic samplers with Teflon® tubes, and stored in clean glass bottles at 4 °C. In the lab, tests were performed to assess the PAC's purification efficiency and process parameters. The optimal PAC dosage was explored through jar tests, adjusting the PAC concentration from 15 to 35 mg/L. Micropollutant removal was assessed at a steady 25 °C, following 15 minutes of agitation at 120 rpm, before filtering the mixed solutions.

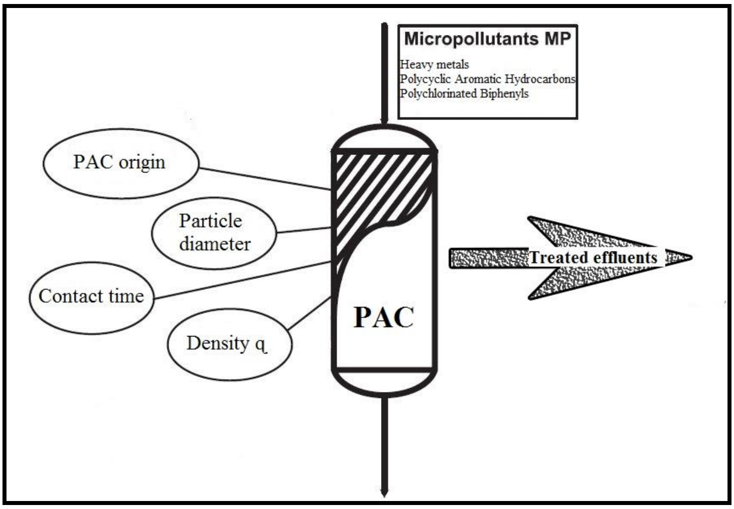

Fig. 1. Scheme of the laboratory scale PAC addition tests.

2.4. WWTP quality parameters

Table 2 presents wastewater quality metrics from the sampling campaigns, covering chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN), along with their removal efficiencies (RE, in %) between raw (RW) and finished water (FW). Average values and standard deviations for each parameter across all campaigns are provided.

Table 2. Conventional wastewater quality parameters in RW and TW effluents.

Parameters	Unit	Raw wastewater	Treated wastewater	Removal Efficiency %
TSS	mg/L	353 ± 52	13.43 ± 2.32	96.15 - 99.00
COD	mg d’O2/L	844.28 ± 69.66	36.92 ± 5.36	95.50 - 98.30
BOD	mg d’O2/L	569.27 ± 15.60	10.09 ± 1.54	97.20 - 98.40
Total Nitrogen	mg/L	85.18 ± 7.85	4.77 ± 0.54	95.25 - 97.23
Total phosphorus	mg/L	8.94 ± 0.35	4.74 ± 0.57	46.80 - 51.17

2.5. Analytical procedures

Our study examined 46 micropollutants from various everyday activities, including 12 heavy metals (HMs), 18 polychlorinated biphenyls (PCBs), and 16 polycyclic aromatic hydrocarbons (PAHs). The HMs include elements like Cu, Zn, and Hg; the PCBs range from PCB-28 to PCB-189; and the PAHs cover compounds from Acenaphthene to Pyrene. Concentrations of PAHs and PCBs were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS), while HMs were assessed through Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES), following methodologies described in earlier research.

3 Results and discussions

3.1. Influence and efficiency of the PAC doses

In the wastewater treatment process, a single variety of powdered activated carbon (PAC), identified as type X, was utilized. To assess its impact on micropollutant elimination, varying dosages of PAC (ranging from 15 to 35 mg/L) were tested across three distinct trials, with each employing a different concentration of PAC (15 mg/L for PAC1, 25 mg/L for PAC2, and 35 mg/L for PAC3). The results indicated that the removal rate of suspended solids improved as the PAC dosage increased, with the PAC's effectiveness enhancing from 38.70% to 92.32%, as shown in Figure 2.

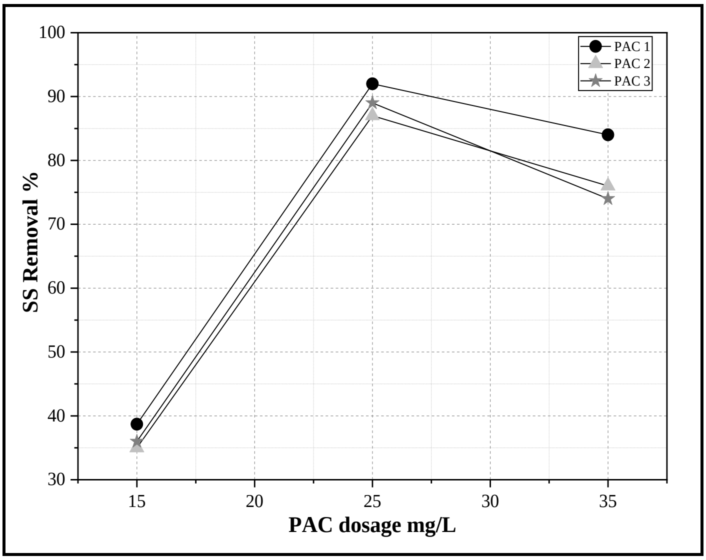

Fig. 2. Removal efficiency of suspended solids using different doses of PAC (X).

The elimination yield increased from 35.65 to 91.30 %, when the dose went from 15 to 25 mg/L. On the other hand, it decreased from 91.30 to 72%, when the dose went from 25 to 35 mg/L. This decrease can be resulted of the lack availability of active pores on the PAC. [50, 51] found the same influence.

3.2. Micropollutants concentrations in raw wastewater

Of the targeted 46 micropollutants, 33 were found in the raw wastewater samples, consisting of a mix of eight PCBs, three heavy metals (arsenic, chromium, and cobalt), and two PAHs (Chrysene and Dibenzo(a,h)Anthracene). Figure 3 illustrates the concentrations of these detected substances across different sampling periods, showcasing a broad spectrum of levels from 0.02 to 850 µg/L. This variability highlights the diverse presence of pollutants: metallic elements showing higher concentrations up to 850 µg/L; a mid-range concentration of 0.09 to 1 µg/L for both high and low molecular weight PAHs; and lower concentrations, 0.01 to 0.09 µg/L, associated with PCBs and certain PAHs, underscoring the complex composition of contaminants in wastewater.

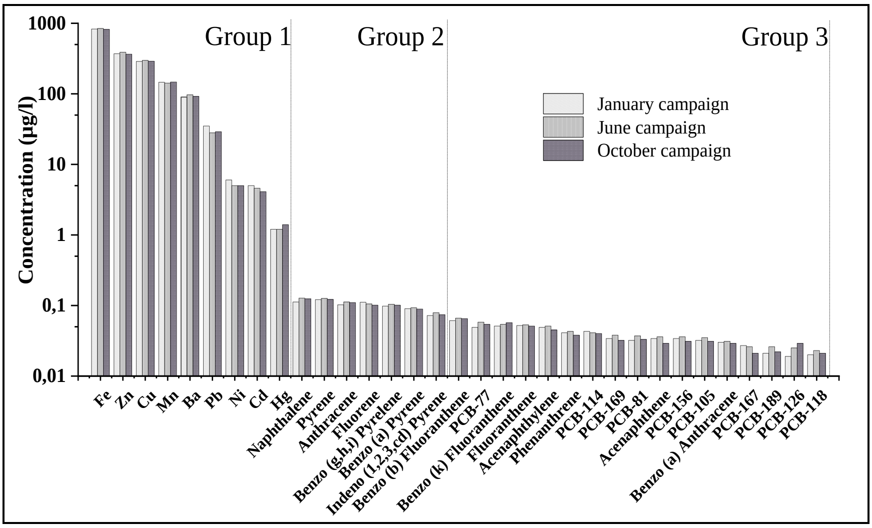

Fig. 3. Micropollutant concentrations in raw wastewater.

3.3. Micropollutants removal by PAC at lab scale

Figure 4 juxtaposes the post-PAC treatment concentrations of various micropollutants (MPs) with those reported in existing literature, revealing a significant reduction in pollutant levels. For 13 compounds, the quantification of elimination yield was not pursued, as their concentrations fell below the limit of quantification (LOQ), mirroring findings reported in scholarly articles. This demonstrates the efficacy of powdered activated carbon (PAC) in the adsorption and subsequent removal of a wide range of micropollutants from wastewater. However, it's important to note that hydrophobicity alone does not fully predict the efficiency of MP removal, highlighting the complexity of PAC adsorption which is influenced by multiple factors and interactions.

Remarkably, the study achieved a removal efficiency exceeding 80% for 16 of the micropollutants, underscoring the potential of PAC treatment in wastewater management. This investigation stands out as the first to evaluate the removal efficiency of such a broad spectrum of 46 MPs, offering insights that largely align with those documented in prior research. Specifically, the comparison with literature suggests a consistency in the observed removal efficiencies, which predominantly range between 50 to 80%. This parallel not only validates the effectiveness of PAC in purifying wastewater of MPs but also emphasizes the reproducibility of these results across different studies, providing a robust foundation for further exploration and optimization of PAC treatment processes.

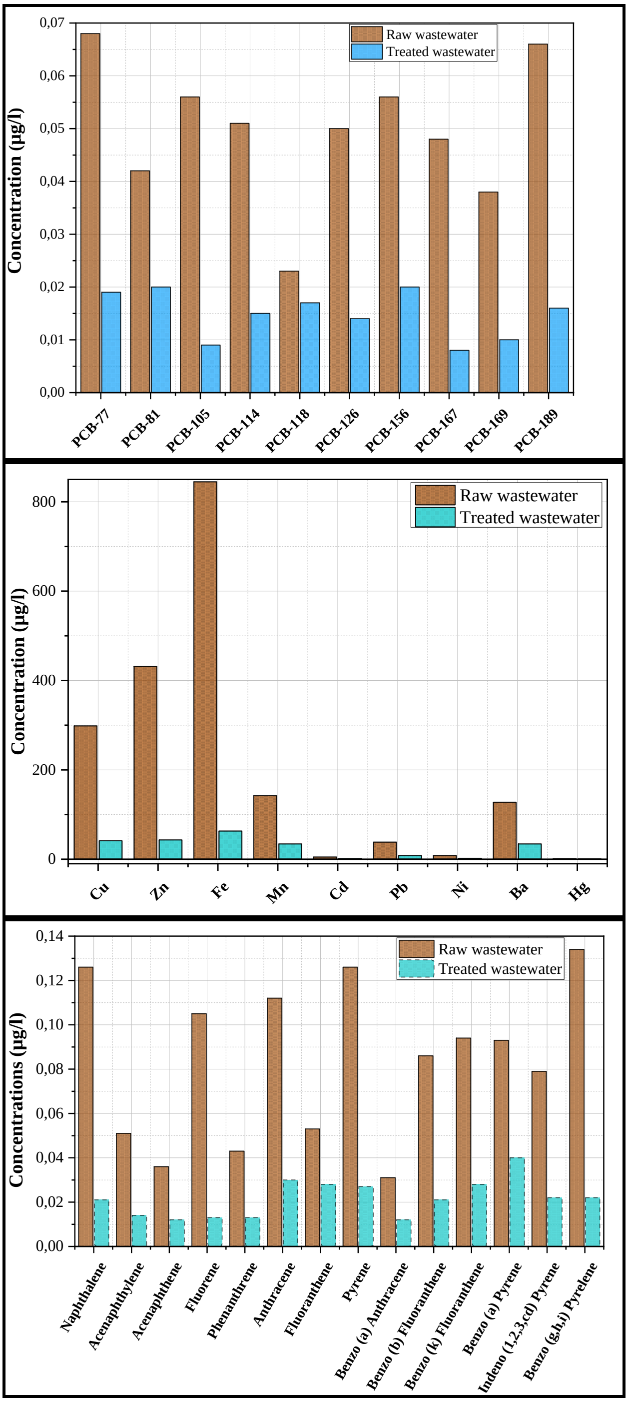

Fig. 4. Micropollutants concentrations in raw wastewater and treated wastewater with powdered activated carbon.

The outcomes of this study categorize the micropollutants into three distinct groups based on their removal efficiency post-PAC treatment, as illustrated in Fig. 5. These categories include compounds that were highly removed with an efficiency exceeding 80%, those with moderate removal rates ranging from 30 to 80%, and compounds that saw minimal removal with efficiencies below 30%. Notably, heavy metals demonstrated the highest removal rates among all categories, with an impressive peak removal efficiency reaching up to 93%. Among these metals, all showed significant removal efficiencies except for manganese (Mn), lead (Pb), and barium (Ba), which did not meet the criteria for the 'strongly removed' category. On the other hand, the rest of the micropollutants, including specific polycyclic aromatic hydrocarbons (PAHs) like Fluoranthene and Benzo(k)Fluoranthene, as well as certain polychlorinated biphenyls (PCBs), namely PCB-105 and PCB-118, fell into the 'moderately removed' bracket. This classification underlines the effectiveness of PAC treatment in significantly reducing the concentration of a wide array of pollutants, albeit with varying degrees of success across different chemical families.

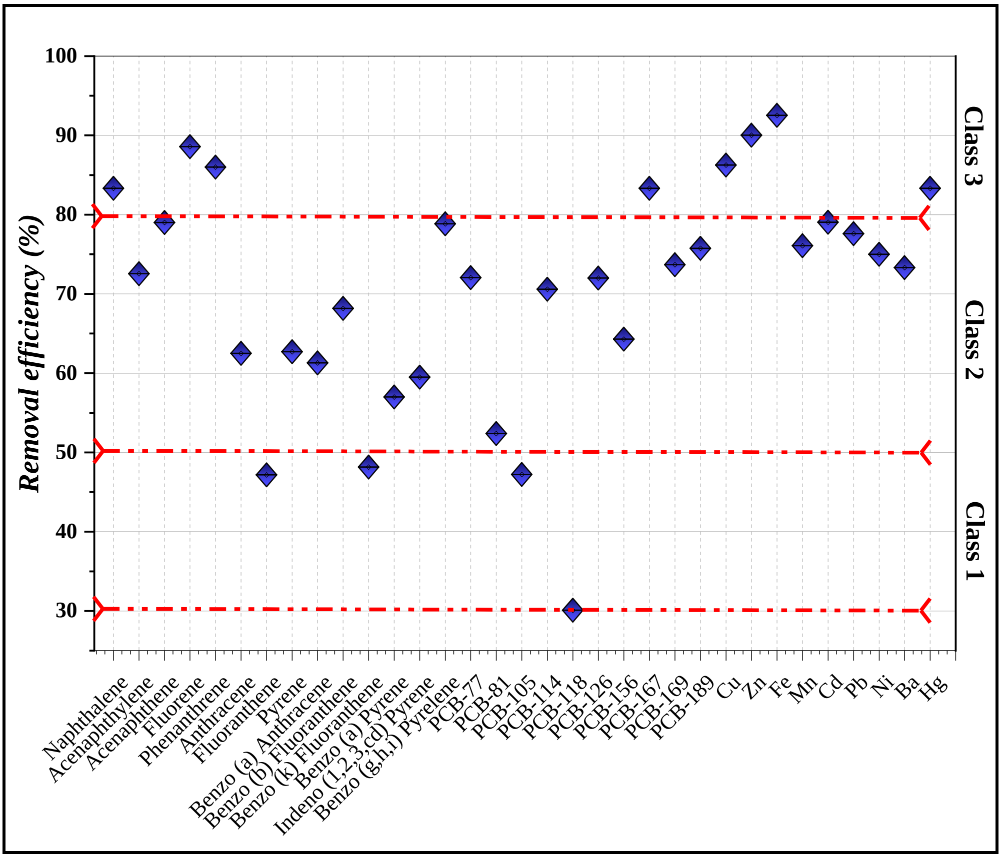

Fig. 5. Removal efficiency of MPs from urban wastewater treated with PAC.

3.4.Comparative contribution of the advanced treatment compared to the conventional process

The integration of powdered activated carbon (PAC) into wastewater treatment processes has markedly improved the removal of micropollutants, underscoring the efficacy of advanced treatment strategies over conventional methods. While PAC significantly enhanced pollutant elimination, its impact varied across different substances; notably, six polycyclic aromatic hydrocarbons (PAHs) showed no change in removal efficiency with

PAC treatment, highlighting that its effectiveness is not universally applicable to all micropollutants. However, no instances of negative removal rates were observed, indicating PAC's beneficial role in overall pollutant reduction.

Further research, including studies combining PAC with ozonation, demonstrates the potential for even greater pollutant removal efficiencies. Such combinations suggest that PAC can be effectively paired with other advanced treatment technologies to tackle a broad spectrum of contaminants, including those resistant to conventional treatment methods. This adaptability of PAC, both as a standalone and a complementary treatment, aligns with the growing necessity for more refined wastewater treatment capabilities, especially in the face of emerging contaminants like pharmaceuticals and personal care products.

Traditional wastewater treatment has primarily focused on reducing organic matter, nutrients, and suspended solids through physical, chemical, and biological processes. However, these conventional methods often fall short in addressing the complex array of micropollutants increasingly found in water bodies. The advent of advanced treatment technologies, including PAC adsorption, ozonation, advanced oxidation processes (AOPs), and membrane filtration, offers a more nuanced approach to pollutant removal, achieving efficiencies often exceeding 90% for a wide variety of contaminants.

The superior performance of advanced treatments highlights their crucial role in mitigating environmental and health risks associated with micropollutant discharge into aquatic ecosystems. This is increasingly important as treated wastewater becomes a valuable resource for various reuse applications, necessitating the removal of harmful contaminants to ensure safety and compliance with quality standards.

In essence, the advancement of wastewater treatment through the incorporation of PAC and other innovative technologies represents a significant leap forward in our ability to effectively manage and eliminate micropollutants. This progress is pivotal for enhancing the sustainability of water management practices, safeguarding public health, and protecting the environment from the potential impacts of untreated wastewater, thereby setting a new standard for wastewater treatment efficacy.

4 Conclusion

The deployment of powdered activated carbon (PAC) in the treatment of urban wastewater presents an approach comparable to other established techniques, demonstrating considerable potential in enhancing pollutant removal. This study investigated the efficacy of a commercially available PAC, referred to as type X, by administering it in various concentrations to assess its impact on the elimination of micropollutants (MPs) from wastewater. The findings revealed a marked improvement in the reduction of MPs, attributing a differential effect of PAC on organic micropollutants (OMPs) and more readily removable micropollutants (MMPs), with the latter experiencing significantly higher removal rates.

The effectiveness of PAC in mitigating the presence of OMPs in wastewater was observed to be moderate to low, suggesting that while PAC is beneficial, its capacity to adsorb these particular compounds is limited. Conversely, MMPs were substantially more affected by PAC treatment, showcasing a strong affinity between PAC and these pollutants, leading to their successful removal. For the majority of the compounds analyzed, the removal efficiency exceeded 60%, underscoring the capability of PAC to significantly reduce pollutant levels in urban wastewater streams.

When considering the broader context of wastewater treatment, the integration of PAC within a combined framework of conventional and advanced treatment processes emerges as a highly effective strategy. The synergistic effect of this integrated approach can elevate removal efficiencies to surpass the 80% threshold. This indicates that while PAC alone offers a valuable means of enhancing pollutant reduction, its full potential is realized when it is part of a comprehensive treatment strategy that leverages both conventional methods and advanced remediation technologies.

This study's findings highlight the versatility and effectiveness of PAC as a treatment medium in the context of urban wastewater management. By carefully selecting the type and dosage of PAC, and integrating it within a holistic treatment framework, wastewater treatment facilities can achieve significant improvements in the quality of treated water. This not only contributes to the protection of aquatic environments by reducing the load of pollutants discharged into natural water bodies but also supports public health objectives by minimizing exposure to hazardous substances. The nuanced understanding of PAC's role in wastewater treatment developed through this research provides a valuable foundation for optimizing treatment protocols and advancing the sustainability of urban water management practices.

References

1. T. Mkilima, Y. Zharkenov, L. Utepbergenova, A. Abduova, N. Sarypbekova, E. Smagulova, G. Abdukalikova, F. Kamidulla, and I. Zhumadilov, Water Cycle, (2024).
2. Y. El Hammoudani, F. Dimane, K. Haboubi, C. Benaissa, L. Benaabidate, A. Bourjila, I. Achoukhi, M. El Boudammoussi, H. Faiz, and A. Touzani, Desalination and Water Treatment, 100190 (2024).
3. S.F. Ahmed, N. Islam, N. Tasannum, A. Mehjabin, A. Momtahin, A.A. Chowdhury, F. Almomani, and M. Mofijur, Chemosphere, **347**, 140648 (2024).
4. B. Cui, H. Rong, T. Tian, D. Guo, L. Duan, F. Nkinahamira, P. Ndagijimana, W. Yan, and R. Naidu, Environmental Research, 118416 (2024).
5. H.A. Shamkhi, M.J. Abdulhasan, S.A. Raheem, H.A.M. Al-Zubaidi, and A.S.K. Janabi, Desalination and Water Treatment, **306**, 63-74 (2023).
6. M. Abily, V. Acuña, L. Corominas, I. Rodríguez-Roda, and W. Gernjak, Journal of Cleaner Production, **415**, 137867 (2023).
7. A.B. Rios-Miguel, T.J. van Bergen, C. Zillien, A.M. Ragas, R. van Zelm, M.S. Jetten, A.J. Hendriks, and C.U. Welte, Chemosphere, 138908 (2023).
8. N.A. Khan, S. Singh, E.A. López-Maldonado, N. Pavithra, P.F. Méndez-Herrera, J.R. López-López, U. Baig, P.C. Ramamurthy, N.M. Mubarak, and R.R. Karri, Desalination, **565**, 116873 (2023).
9. V. Fernández-Fernández, M. Ramil, and I. Rodríguez, Chemosphere, 139094 (2023).
10. C. Silva, C.M. Almeida, J.A. Rodrigues, S. Silva, M. do Rosário Coelho, A. Martins, R. Lourinho, E. Cardoso, V.V. Cardoso, and M.J. Benoliel, Journal of Water Process Engineering, **54**, 103985 (2023).
11. M.S. Ali, J.T. Orasugh, S.S. Ray, and D. Chattopadhyay, *Wastewater remediation for reuse through emerging technologies*, in *Development in Wastewater Treatment Research and Processes*. 2023, Elsevier. p. 61-77.
12. N. Hardyanti, H. Susanto, F.A. Kusuma, and M.A. Budihardjo, Polish Journal of Environmental Studies, **32**, 981-989 (2023).

13. T. He, Z. Liu, W. Zhou, X. Cheng, L. He, Q. Guan, and H. Zhou, Journal of Environmental Management, **323**, (2022).

14. A. Ait Mansour, B. El-Haitout, R.J. Adnin, H. Lgaz, R. Salghi, H.-s. Lee, M.R. Alhadeethi, M. Messali, K. Haboubi, and I.H. Ali, Metals, **13**, 797 (2023).

15. A. Abouabdallah, Y. El Hammoudani, F. Dimane, K. Haboubi, K. Rhayour, and C. Benaissa, Ecological Engineering and Environmental Technology, **24**, 170-182 (2023).

16. I. Achoukhi, Y. El Hammoudani, F. Dimane, K. Haboubi, A. Bourjila, C. Haboubi, C. Benaissa, A. Elabdouni, and H. Faiz, Journal of Ecological Engineering, **24**, 12-31 (2023).

17. K. Andaloussi, H. Achtak, C. Nakhcha, K. Haboubi, and M. Stitou, Moroccan Journal of Chemistry, **9**, 9-3 (2021) 513-529 (2021).

18. D. Bouknana, S. Jodeh, M. Sbaa, B. Hammouti, M. Arabi, A. Darmous, M. Slamini, and K. Haboubi, Environmental Monitoring and Assessment, **191**, (2019).

19. A. El Abdouni, S. Bouhout, I. Merimi, B. Hammouti, and K. Haboubi, Casp. J. Environ. Sci., **19**, 423-429 (2021).

20. A.E. Abdouni, S. Bouhout, I. Merimi, B. Hammouti, and K. Haboubi, Caspian Journal of Environmental Sciences, **19**, 423-429 (2021).

21. M. Elazzouzi, K. Haboubi, M. Elyoubi, and A. El Kasmi, ES Energy & Environment, **5**, 66-74 (2019).

22. M. Elazzouzi, K. Haboubi, M.S. Elyoubi, and A. El Kasmi, Arabian Journal of Chemistry, **14**, (2021).

23. Y. Fernine, N. Arrousse, R. Haldhar, C.J. Raorane, S.-C. Kim, F. El Hajjaji, M.E. Touhami, M. Beniken, K. Haboubi, and M. Taleb, Journal of the Taiwan Institute of Chemical Engineers, **140**, 104556 (2022).

24. C. Haboubi, E.H. Barhdadi, K. Haboubi, Y.E. Hammoudani, Z. Sadoune, A.E. Abdouni, and F. Dimane, Advances in Science and Technology Research Journal, **18**, 71-77 (2024).

25. K. Haboubi, A. El Abdouni, Y. El Hammoudani, F. Dimane, and C. Haboubi, Environmental Engineering and Management Journal, **22**, 1813-1820 (2023).

26. S. Tighadouini, S. Radi, A. Elidrissi, K. Haboubi, M. Bacquet, S. Degoutin, M. Zaghrioui, and Y. Garcia, Beilstein Journal of Nanotechnology, **10**, 262-273 (2019).

27. A. Touzani, Y. El Hammoudani, F. Dimane, M. Tahiri, and K. Haboubi, Ecological Engineering & Environmental Technology, **25**, 57-69

28. O. Saadi, N. Nouayti, A. Nouayti, F. Dimane, and K. Elhairechi, Groundwater for Sustainable Development, **14**, 100639 (2021).

29. H.E. Hassouni, A. Elyousfi, F. Benhiba, N. Setti, A. Romane, T. Benhadda, A. Zarrouk, and A. Dafali, Inorganic Chemistry Communications, **143**, 109801 (2022).

30. A. Elyoussfi, H. Outada, J. Isaad, H. Lrhoul, A. Salhi, and A. Dafali, Int. J. Corros. Scale Inhib, **12**, 722-740 (2023).

31. A. Salhi, A. Elyoussfi, I. Azghay, A. El Aatiaoui, H. Amhamdi, M. El Massaoudi, M. Ahari, A. Bouyanzer, S. Radi, and S. El barkany, Inorganic Chemistry Communications, **152**, (2023).

32. A. Elabdouni, K. Haboubi, N. Bensitel, S. Bouhout, K. Aberkani, and M.S. El Youbi, Moroccan Journal of Chemistry, **10**, 191-202 (2022).

33. A. Elabdouni, K. Haboubi, I. Merimi, and M. El Youbi, Materials Today: Proceedings, **27**, 3145-3150 (2020).

34. F. Dimane, K. Haboubi, I. Hanafi, and A. El Himri, European Scientific Journal, **12**, 272 (2016).

35. E. Derwich, Z. Benziane, and L. Benaabidate, Environ. Earth Sci., **63**, 839-846 (2011).

36. C. Benaissa, B. Bouhmadi, A. Rossi, and Y. El Hammoudani. Hydro-chemical and bacteriological Study of Some Sources of Groundwater in the GHIS-NEKOR and the BOKOYA Aquifers (AL HOCEIMA, MOROCCO). in Proc of The 4th Edition of International Conference on Geo-IT and Water Resources. 2020.

37. C. Benaissa, B. Bouhmadi, A. Rossi, Y. El Hammoudani, and F. Dimane, Ecological Engineering & Environmental Technology, **23**, 31-44 (2022).

38. C. Benaissa, A. Rossi, B. Bouhmadi, Y. El Hammoudani, and F. Dimane. Assessment of the physicochemical and bacteriological quality of water source and a well in Bakoya aquifer, northern Morocco. in E3S Web of Conferences. 2024. EDP Sciences.

39. S. Bouhout, K. Haboubi, A. El Abdouni, Y. El Hammoudani, C. Haboubi, F. Dimane, I. Hanafi, and M.S. Elyoubi, Journal of Ecological Engineering, **24**, (2023).

40. S. Bouhout, K. Haboubi, Y.E. Hammoudani, A.E. Abdouni, C. Haboubi, F. Dimane, I. Hanafi, and M.S. Elyoubi, Ecological Engineering and Environmental Technology, **25**, 22-45 (2024).

41. A. Bourjila, F. Dimane, M. Ghalit, M. Taher, S. Kamari, Y. El Hammoudani, I. Achoukhi, and K. Haboubi, Water Cycle, **4**, 104-119 (2023).

42. F. Dimane and Y. El Hammoudani, Materials Today: Proceedings, **45**, 7742-7746 (2021).

43. Y. El Hammoudani and F. Dimane, Environ. Eng. Res., **0**, 0 (2020).

44. Y. El Hammoudani and F. Dimane, Environ. Chall., **5**, 1-8 (2021).

45. Y. El Hammoudani, F. Dimane, and H. El Ouarghi, Environ. Water. Sci. Res. Public Health. Territ. Intellig., **3**, 47-52 (2019).

46. Y. El Hammoudani, F. Dimane, and H. El Ouarghi, Environmental Engineering and Management Journal, **20**, 995-1002 (2021).

47. Y. El Hammoudani, F. Dimane, and H. El Ouarghi. Fate of Selected Heavy Metals in a Biological Wastewater Treatment System. in Euro-Mediterranean Conference for Environmental Integration. 2019. Springer.

48. Y. El Hammoudani, F. Dimane, K. Haboubi, A. Bourjila, C. Benaissa, I. Achoukhi, and C. Haboubi, Environmental Engineering & Management Journal (EEMJ), **22**, (2023).

49. C. Haboubi, Y. El Hammoudani, N. Jaradat, S. Jodeh, K. Haboubi, and F. Dimane, Palestinian Medical and Pharmaceutical Journal (Pal. Med. Pharm. J.), **9**, None-None (2023).

50. S. Platz, U. Menzel, and M. Wett, Proceedings of the Water Environment Federation, WEFTEC 2012: Session 51 through Session, **60**, 3805-3816 (2012).

51. F. Sher, K. Hanif, A. Rafey, U. Khalid, A. Zafar, M. Ameen, and E.C. Lima, J. Environ. Manage., **278**, 111302 (2021).