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STUDIES AND RESEARCH ON IMPROVING ENVIRONMENTAL PROTECTION AND REMEDIATION PROCESSES

SUMMARY

The habilitation thesis “*Studies and Research on Improving Environmental Protection and Remediation Processes*” synthesizes a complex and interdisciplinary scientific trajectory, developed at the intersection of materials science, advanced physicochemical processes, sustainable biomaterials, the modeling of complex systems, and direct applications in *Environmental Engineering*. Structured around three fundamental directions, materials and biomaterials for remediation, advanced processes for pollutant treatment, and fractal/multifractal modeling of natural systems, the thesis offers an integrated perspective on how fundamental and applied research can generate efficient solutions to contemporary environmental challenges.

The first direction highlights the development of advanced materials based on modified clays, with a dual role as adsorbents and catalysts. Clays functionalized with Boltorn dendrimers, metal ions, or pillared structures demonstrate high retention and degradation capacities for emerging pollutants such as phthalates, phenolic compounds, TNT, or industrial dyes. The research includes detailed characterization (SEM, XRD, FTIR, BET), correlations between microstructure and physicochemical performance, and demonstrations of applicability in real pollution-affected systems. The original contributions target improvements in selectivity and efficiency of adsorption processes as well as the integration of materials into advanced oxidation processes, such as catalytic ozonation.

The second direction expands the approach to biomaterials derived from natural resources, particularly fishery waste (*Cyprinus carpio*). Fish scales and swim bladders, along with their vanadium-modified variants, are shown to be effective biosorbents and active

catalysts for degrading persistent organic contaminants such as Malachite Green. This research direction promotes the principles of the circular economy and underscores the potential of underutilized biological resources in depollution processes, emphasizing sustainability, accessibility, and the practical applicability of the proposed technologies.

The third direction introduces a conceptual and theoretical component centered on multifractal modeling and the analysis of complex systems, with direct implications for understanding environmental processes. The studies dedicated to dynamical synchronization, order–disorder transitions, and informational geometries provide advanced tools for describing scale dependence, nonlinearity, and emergent behaviors in natural and technical systems. This theoretical framework is not presented as an abstract domain, but as a solid mathematical support for optimizing transport, reaction, and diffusion processes frequently encountered in *Environmental Engineering*.

An important component of the thesis is the applied analysis of groundwater quality near closed landfills, involving the monitoring of physicochemical parameters, heavy metals, and microplastics. The results emphasize the persistence of contamination, the influence of hydrometeorological conditions on pollutant migration, and the need for integrated evaluation and remediation strategies. This research reinforces the applied dimension of the thesis, demonstrating the relevance of the proposed solutions in real-world contexts.

Overall, the thesis reflects a coherent, and results-oriented scientific trajectory that combines rigorous experimentation, advanced modeling, and practical applicability. The contributions illustrate a research model that integrates creativity, analytical rigor, and environmental responsibility, forming a solid foundation for future professional development in the academic field. The proposed directions, demonstrated impact, and interdisciplinary perspective confirm the capacity to coordinate complex scientific activities and to develop research programs relevant to current and future challenges in *Environmental Engineering*.