DESIGN AND FABRICATION OF A FIELD-PORTABLE SAMPLER AND MULTI-MODAL ANALYSIS OF RESPIRABLE BIOLOGICAL PARTICLES

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Abstract

The Indo-Gangetic Plain faces a public health crisis due to elevated air pollutants, yet ambient bioaerosols, particularly pollen, remain understudied because of the absence of indigenous monitoring infrastructure; conventional aerobiological methods rely on costly imported instruments and labour-intensive manual microscopy. This research addresses these gaps through a field-portable inertial impactor, atmospheric dispersion analysis using PM_{10} as a proxy for coarse bioaerosol particles, and an AI-enabled, label-free identification framework.

The first component involved the design and development of a field-portable inertial impactor optimized for ambient pollen collection (2.5–50 µm). Key geometric parameters, including the jet-to-plate distance ratio (S/W = 1.5) and nozzle width, were established through analytical methods, while Computational Fluid Dynamics (CFD) and Discrete Phase Model (DPM) simulations characterized internal aerodynamics and validated the theoretical cut-off diameter. The numerical model demonstrated a capture efficiency of 54.3% at the 2.5 µm threshold, rising to over 98% for particles ≥10 µm, with particle trajectory completion rates exceeding 99.5%, confirming close agreement between the simulated and physical impaction mechanisms.

The study assessed a label-free identification method based on Evanescent Wave Scattering Microscopy (EWSM), which offers superior signal-to-background ratios relative to conventional

bright-field microscopy and resolves the distinctive morphological scattering signatures of pollen grains. A two-stage deep learning framework was developed, combining a high-recall RT-DETR detector (Recall = 0.823) for localization with an EfficientNet-B0 expert classifier for species-level identification. A human-in-the-loop, data-centric refinement process substantially improved system performance, raising the F1-score from a baseline of 0.277 to 0.537, demonstrating that while single-stage detectors suffice for general localization, expert classification is essential for the fine-grained identification demanded by comprehensive aerobiological analysis.

The study further examined the dispersive and advective behaviour of coarse particles, using PM_{10} as a surrogate for bioaerosols owing to the absence of real-time pollen data in Delhi. Applying a particulate matter reduction (PMR) methodology alongside bivariate polar plots, the study identified pronounced seasonal contrasts in pollutant transport: winter months were dominated by advective transport enabling long-range movement even under low mixing heights (<400 m), while summer concentrations were primarily governed by wind-induced resuspension.

The research concludes that integrating indigenous hardware, atmospheric modelling, and AI-driven optics provides a scalable solution for aerobiological monitoring in India. The major contributions of this work include the design of a validated, low-cost, portable bioaerosol sampler, a quantitative framework for understanding dispersion of coarse particles, and implementation of a semi-supervised, EWSM-based deep learning framework for automated pollen classification. These advancements lay the groundwork for real-time, IoT-integrated bioaerosol monitoring networks, offering a viable pathway to mitigate respiratory health risks and enhance environmental surveillance in highly polluted urban regions.