BRIEF REPORT

APEX: A Web-Based Tool for Assessing Long-Term Outdoor $PM_{2.5}$ Exposure—Brief Report

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ABSTRACT

Long-term exposure to ambient fine particulate matter air pollution ($PM_{2.5}$) is a major risk factor for lung cancer and other chronic diseases. However, assigning individualized long-term exposure estimates, both at the point of care and in epidemiologic research, remains a methodological challenge due to limited tools for integrating residential history with air pollution data. As a result, most studies estimate exposure based only on a participant's last recorded address. Here, we describe and demonstrate the use of the Air Pollution EXposure (APEX) tool, a web-based application that provides individual annual estimates for $PM_{2.5}$ exposure from 1998 to 2024 based on a user-provided residential history. APEX can collect address histories through a user-friendly web interface to collect worldwide addresses with autocompletion and interactive map facilitating recall of partial addresses. Addresses are geocoded and linked to annual surface-level $PM_{2.5}$ estimates. APEX also supports both single-entry and batch-processing entry modes for integration in clinical and research workflows. APEX outputs annual $PM_{2.5}$ exposure values, geocoded address logs, and graphical summaries. APEX-derived exposure estimates have been used to support an epidemiologic analysis evaluating the association between $PM_{2.5}$ and lung cancer risk. APEX enables scalable, reproducible, and clinically applicable $PM_{2.5}$ exposure assessment, facilitating personalized evaluation for risk assessment and epidemiologic research for lung cancer, cardiovascular disease, and other conditions associated with air pollution.

Keywords: Air pollution; $PM_{2.5}$ exposure; Environmental epidemiology; Lung cancer risk

Impact Statement

Estimating long-term $PM_{2.5}$ exposure from residential history is often time consuming, error prone, and difficult to integrate with reliable historical $PM_{2.5}$ data sets. Currently, no tools provide a streamlined, scalable solution for this task. The Air Pollution EXposure (APEX) tool addresses this gap by offering a user-friendly, non-technical platform to capture complete error-free residential histories and compute annual $PM_{2.5}$ exposure estimates. Its intuitive interface and batch-processing capabilities enable clinicians and researchers, regardless of technical background, to efficiently obtain individualized exposure data for clinical or epidemiologic applications.

Introduction

In 2013, the International Agency for Research on Cancer classified outdoor air pollution and particulate

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matter (PM) with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) in outdoor air pollution as carcinogenic to humans (International Agency for Research on Cancer group 1) and as a leading cause of lung cancer, other cancers, and a range of other diseases, including cardiovascular, respiratory, and neurologic disorders.[1,2] Globally, exposure to outdoor air pollutants is the second most important lung cancer risk factor, after tobacco smoking.[3] As tobacco use declines, the number of estimated attributable lung cancer deaths from air pollution has increased by nearly 30% since 2007.[4] Understanding and integrating environmental exposures such as $PM_{2.5}$ into risk-prediction models has become increasingly important, especially for individuals who have never smoked or formerly smoked.[5] However, estimating individual exposure to ambient air pollution remains a challenge. The greatest obstacle has been obtaining residential addresses in part because no tool facilitated their collection. Other barriers include incomplete or error-prone residential histories, difficulty recalling exact locations, and the technical expertise required to link addresses with historical $PM_{2.5}$ data. These obstacles have limited the ability of many studies to incorporate individual-level $PM_{2.5}$ exposure into epidemiologic analyses or risk-prediction tools.

To address this gap, we developed and tested the APEX tool, a user-friendly web application that estimates annual $PM_{2.5}$ exposure based on residential history. APEX provides $PM_{2.5}$ estimates globally and works in any language supported by the Google Maps API. APEX is designed to support both clinical and research applications by enabling scalable and reproducible exposure assessment without requiring technical expertise.

Methods

APEX supports the following two submission types: (1) single patient for individual-level analysis, such as for use in a lung cancer risk calculator, and (2) batch processing for research applications for large cohorts. Both use a shared backend algorithm but differ in interface and intended use.

APEX's backend was implemented in Python. $PM_{2.5}$ estimates are derived from the Atmospheric Composition Analysis Group's V5.GL.06 data set at $0.01^{\circ} \times 0.01^{\circ}$ resolution from 1998 to 2024.[6,7] Geocoding is performed using the geopy package and the Google Maps API. To estimate exposure, the tool applies an 11-km spatial buffer around each address using a Haversine distance filter. This buffer captures nearby grid points, accounting for both real-world mobility (e.g., commuting) and the coarse spatial resolution of $PM_{2.5}$ data. Monthly values are weighted evenly. In cases of overlapping addresses during the same month, values are averaged.

Using APEX, a health care provider or research assistant can collect a patient's or participant's residential history from birth. The APEX input form includes (1) the patient or participant ID, (2) the study ID (for research studies), and (3) a Google Maps API key. Once verified, the API key enables address autocompletion to minimize typographic errors. For individuals who are unable to recall an exact address, the API key also enables an interactive map that allows users to select locations visually using recognizable landmarks in the neighborhood to generate a geocodable address. An example of this interface is found in Figure 1. For single-participant entries, APEX outputs a table of annual $PM_{2.5}$ exposure values dated back to 1998 when accurate $PM_{2.5}$ data became available, a geocoded address table for data integrity, and a graphical summary of the results (Fig. 2).

The batch submission form supports cohort-wide or retrospective analyses. It accepts spreadsheets (.xls, .xlsx, or .csv) of time-stamped residential histories for multiple individuals formatted to APEX specifications. Templates and formatting instructions are provided on the Instructions page of the website. Any entries missing latitude and longitudes are automatically geocoded using a user-supplied Google Maps API key. For batch submissions, APEX returns a downloadable .csv file containing annual exposure estimates by participant.

APEX is an open-access tool accessible at apex.bccrc.ca. All submitted data are not stored on the host server. All results are returned to the user only to preserve privacy and confidentiality.

APEX was piloted at the British Columbia Cancer Research Institute in several ongoing studies. All participants provided informed consent and resided in British Columbia at the time of the study which was approved by the UBC BC Cancer Research Ethics Board.

Results

The single-participant entry feature was used to estimate long-term $PM_{2.5}$ exposure based on residential histories collected during participant interviews in a study of individuals with incidental pulmonary nodules and in a pilot screening study of people who had never smoked tobacco. On average, participants reported five addresses, and a complete $PM_{2.5}$ exposure report could be generated in 5 to 8 minutes. Most of this time was devoted to discussing and verifying address timelines with participants; the actual data entry and computation within APEX required only a small fraction of the total time.

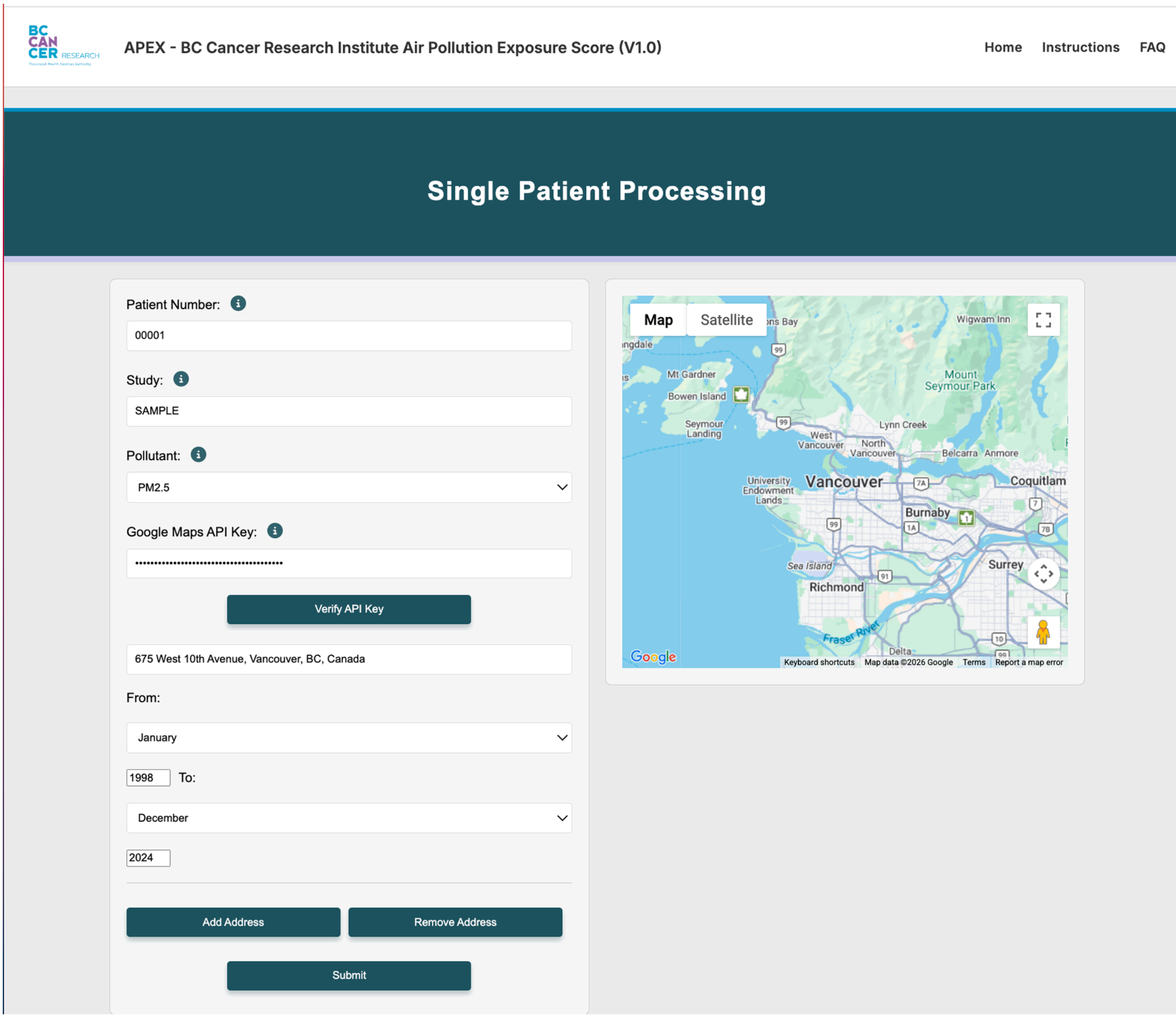

Figure 1. The APEX single-participant input form includes the fields Patient Number for a patient identifier, Study for a study name if applicable, Google Maps API Key field, to enable address autocompletion, and the interactive map and fields for entering the dates of residence. Users can add and remove addresses as necessary. APEX, Air Pollution Exposure.

The batch-processing feature was trialed in a cohort of 886 patients with lung cancer, including 321 who had never smoked, 467 who had smoked in the past, and 98 who were still actively smoking at the time of the interview. The results of the $PM_{2.5}$ exposure are found in Figure 3.

Discussion

We previously reported that patients with lung cancer in British Columbia who had never smoked had substantially higher exposure to outdoor $PM_{2.5}$ compared with patients with lung cancer who had ever smoked, particularly for females of Asian ethnicity.[8] Despite the importance of air pollution as a risk factor, no formal risk-prediction models used for lung cancer screening, such as PLCOm2012, LLP, LCRAT, or Bach, include ambient $PM_{2.5}$ and are predominantly calibrated for ever-smokers, providing limited applicability for people who have never- or ever-smoked. This is largely because of the lack of a practical tool for assessing long- and short-term individual-level exposure.[5,9] To address this, we developed a tool suitable for both face-to-face interviews and research applications. Although a detailed analysis of $PM_{2.5}$ exposure in people who have never- or ever- smoked is beyond the scope of this report, the exposure patterns found in Figure 3 raise the intriguing possibility of both long-term genomic effects and shorter-term cancer promotion, as proposed by Hill et al.[10] and Chen et al.[11]

Despite its utility, APEX has limitations at this time. It currently requires a Google Maps API key for geocoding and enabling features that assist with address entry, which may

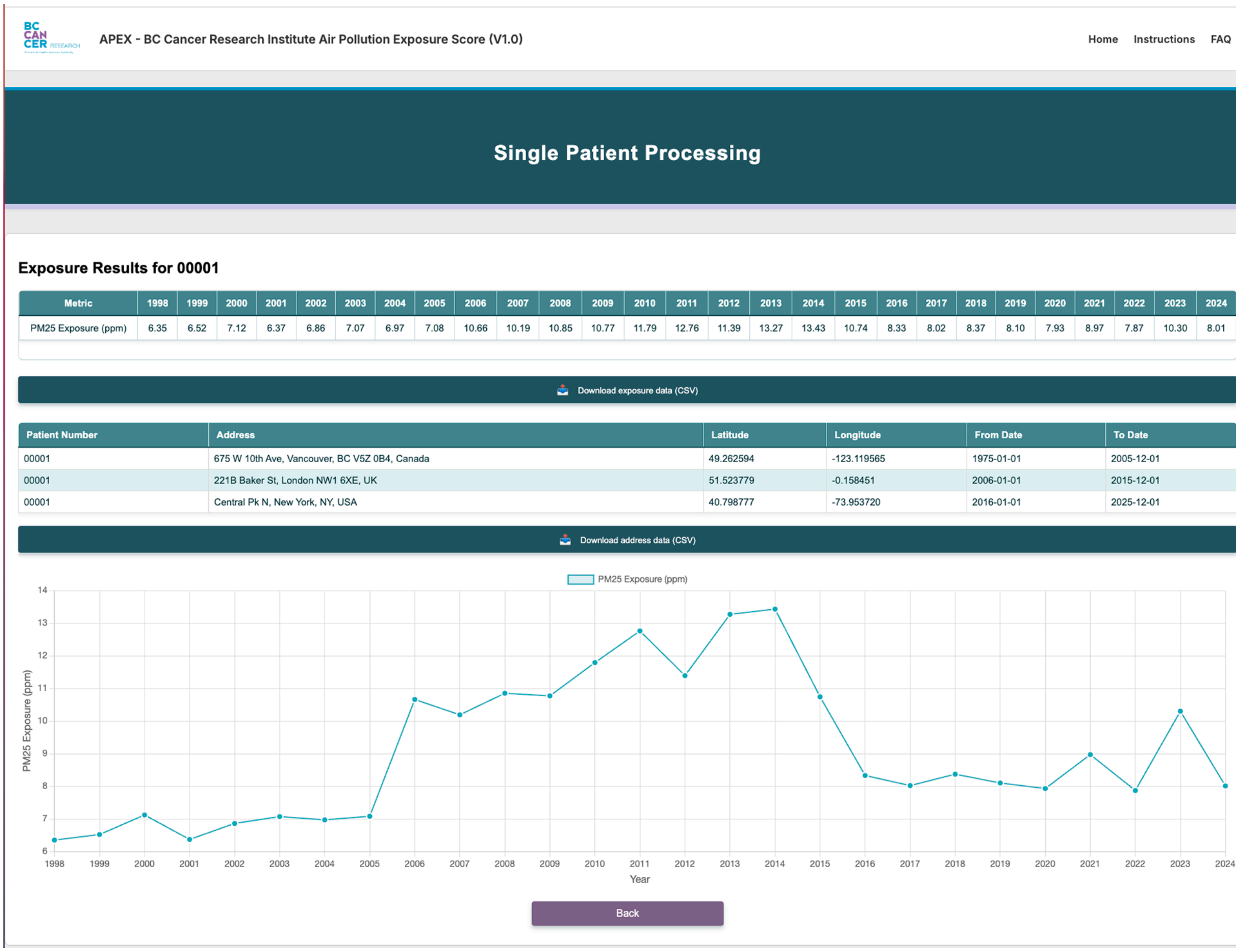

Figure 2. Example of the APEX results page for a single participant. The exposure results are presented in tabular and graphical form. An address table that includes the geocoded latitude and longitude is returned for data integrity and can be saved for future use if needed. The results are downloadable direct to a .csv file and are not stored on any servers. APEX, Air Pollution Exposure.

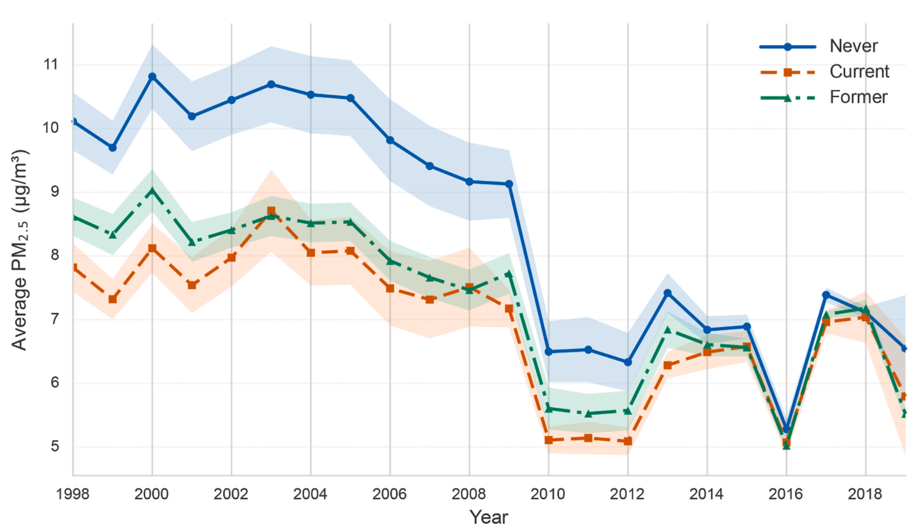

Figure 3. Averaged exposure estimates in a cohort of 886 patients with lung cancer estimated with APEX. There were 321 patients who had never smoked cigarettes, 467 patients who formerly smoked cigarettes, and 98 patients currently smoking at the time of diagnosis. Patients with lung cancer who had never smoked cigarettes had higher $PM_{2.5}$ exposure than the other groups. APEX, Air Pollution Exposure.

present a barrier in some settings. The APEX website has detailed instructions on how to obtain a key and use this tool. At present, APEX supports only one data set from the Atmospheric Composition Analysis Group, with fixed spatial and temporal resolution. Future versions may allow users to select from different data sets (e.g., V6.GL.02.02), choose finer spatial resolution, or toggle between annual and monthly exposure estimates. However, these enhancements would increase computational overhead. Additional planned extensions include support for other environmental exposures such as radon or household air pollution from use of solid fuels or cooking. It is also important to note that APEX is dependent on the ongoing availability and updates of data sets from the Atmospheric Composition Analysis Group or others in the public domain.

Currently, APEX considers only residential addresses, which limits its ability to account for other key locations such as workplaces or schools. However, for a typical individual—assuming 8 hours at work, 2 hours commuting or elsewhere, and 36 weekend hours at home—approximately 63% of time is spent at home, making it the most relevant location for ambient exposure. To account for daily mobility, APEX applies a 10-km spatial buffer around each address, capturing exposures from nearby areas where individuals may work or spend time. Future versions could incorporate additional locations, such as workplaces or schools, and allow users to customize the spatial buffer for averaging $PM_{2.5}$ values.

In conclusion, we present APEX, a user-friendly, publicly available tool for assessing multi-year $PM_{2.5}$ exposure. APEX facilitates recall and accurate recording of past residential addresses through an interactive Google Map and address autocompletion. This tool enables researchers to incorporate outdoor air pollution exposure into epidemiologic analyses and potentially enable clinicians to incorporate exposure into personalized risk evaluations with greater ease and accuracy.

CRediT Authorship Contribution Statement

Clinton H. Durney: Conceptualization, Software, Validation, Writing – original draft, Writing – reviewing & editing.

Aadetri Tawara: Software, Writing – reviewing & editing.

Michael Brauer: Conceptualization, Writing – reviewing & editing.

Sukhinder Atkar-Khattra: Data curation, Project administration, Writing – reviewing & editing.

Renelle Myers: Resources, Writing – reviewing & editing.

Rafael Meza: Conceptualization, Supervision, Writing – reviewing & editing, Funding acquisition.

Stephen Lam: Conceptualization, Supervision, Writing – reviewing & editing, Funding acquisition.

Data Availability Statement

The APEX application is hosted by the British Columbia Cancer Research Institute. Processed output files are provided for downloading after form submission. Annual $PM_{2.5}$ concentration data (Version V5.GL.06) were obtained from the Atmospheric Composition Analysis Group at Washington University in St. Louis. These data are publicly available at: https://www.satpm.org/v5-gl-06 in 0.1° × 0.1° and 0.01° × 0.01° resolutionhttps://www.satpm.org/v5-gl-06in 0.1° × 0.1° and 0.01° × 0.01° resolution.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work the lead author used ChatGPT (OpenAI) in order to improve readability and language clarity of the draft manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Disclosure

The authors declare no conflict of interest.

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