Enhancing Government Capacity for Air Quality Management in the Philippines through Geospatial Technologies: A Case of Project AiRMoVE

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Abstract

Air quality management is crucial in the Philippines due to its profound implications for public health, ecosystems, and sustainable development. Project AiRMoVE, short for the *Ambient Air Remote Sensing, Modeling, and Visualization Environment* project, aims to enhance air quality management through engineering solutions and geospatial technologies such as remote sensing (RS), geographic information systems (GIS) and numerical modeling. Implemented by the University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP TCAGP), Project AiRMoVE collaborates with key stakeholders to identify attainment and non-attainment areas in the National Capital Region (NCR) for air quality monitoring. This paper provides an overview of Project AiRMoVE's objectives, methodologies, and outcomes, emphasizing the significance of RS and GIS in revolutionizing air quality monitoring and management. It underscores a systematic approach adopted in enhancing government capacity for air quality management -- a combination of workshops, technical trainings, and stakeholders' forums.

1. Introduction

1.1 Air quality management in the Philippines

Given its significant implications for public health, ecosystems, and sustainable development, air quality management holds exceptional importance in the Philippines. As urbanization and industrialization accelerate, effective monitoring and management of air quality become increasingly urgent. Project AiRMoVE, short for *Ambient Air Remote Sensing, Modeling, and Visualization Environment*, emerges as a significant initiative in addressing this need and aims to bolster the capacity of the Philippine government and stakeholders in air quality management through advanced technologies such as remote sensing (RS) and geographic information systems (GIS).

In the National Capital Region (NCR), the epicenter of Philippine governance and economy, the Department of Environment and Natural Resources - Environmental Management Bureau (DENR-EMB) oversees the monitoring and reporting of ambient air quality. Collaboratively, through the EMB-NCR office and the NCR Airshed Governing Board, sixteen (16) cities and one (1) municipality (in Figure 1) actively participate in monitoring air pollution levels in the region.

The NCR, characterized by a dense population and intense economic activities, experiences distinct wet and dry seasons that profoundly impact air quality dynamics. Despite the availability of real-time air quality data through the EMB-NCR Air Quality Data Portal, existing platforms often face limitations in handling extensive geographic datasets and conducting comprehensive time-series analysis. These challenges underscore the necessity for further technological advancements to enhance air quality monitoring and management efforts.

1.2 About Project AiRMoVE

Implemented by the University of the Philippines Training Center for Applied Geodesy and Photogrammetry (UP TCAGP) from January 2022 to January 2024, Project AiRMoVE aims to support the work of EMB in identifying attainment and non-attainment areas in NCR for air quality monitoring using combinations of RS, GIS, and numerical modeling techniques. The project's objectives span the development of workflows and methodologies for estimating ambient air pollution, the design and establishment of infrastructure for data collection and WebGIS server, and the creation of an online platform for data sharing, analysis, visualization, and reporting.

Project AiRMoVE stands as a collaborative effort involving key stakeholders such as the EMB, the Philippine Space Agency (PhilSA), the Partnership for Clean Air, Inc. (PCA), and partners in the academe working on related projects such as the Center for Air Research in Urban Environments (CARE) which the University of the Philippines also implements. Focused initially on the NCR, Project AiRMoVE addresses the pressing need for improved air quality reporting systems by leveraging state-of-the-art technologies and innovative webGIS platforms.

In this paper, we provide an overview of Project AiRMoVE's objectives, methodologies, and outcomes, emphasizing the significance of RS and GIS in enhancing air quality monitoring and management. Project AiRMoVE conducted a comprehensive review of related literature and implemented geospatial tools in its workflows, elucidating a systematic approach for enhancing government capacity in managing air quality.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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1.3 Project Framework

The project framework, illustrated in Figure 2, provides a structured approach to guide research tasks centered on geospatial techniques encompassing database management, air quality modeling, and web platform development. These efforts aim to generate research outputs that can inform policy recommendations, aiding local government units in crafting tailored clean air action plans. Notably, the project focuses on leveraging existing monitoring stations equipped with active sensors for in-situ measurements, thus excluding field surveys and pollution control methods application in its 2-year implementation.

Drawing upon global initiatives, several projects have pioneered decision support and environmental monitoring systems, often adhering to geospatial data standards established by the Open Geospatial Consortium (OGC). For example, a distributed web-services-based computing environment called DataFed (Husar et al., 2008) provided a wealth of datasets for air quality management applications emphasizing accessibility and interoperability through OGC protocols. A similar platform, the Goddard Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) Air Quality Online Tool project by NASA, showcases the transformative potential of web-based technologies in visualizing air quality data (Prados et al., 2010).

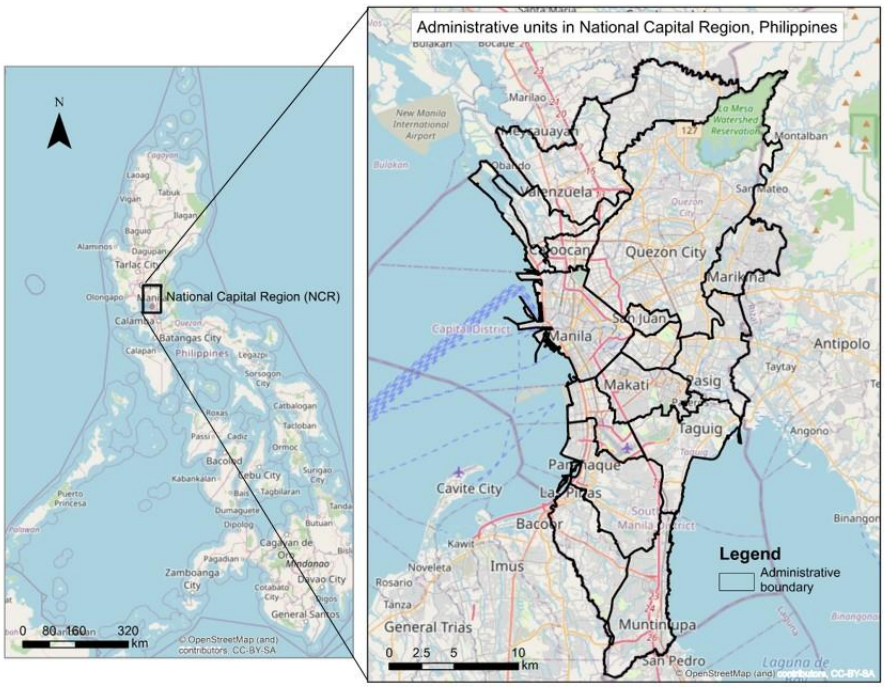

Figure 1. Study area of Project AiRMoVE (Base map source: OpenStreetMap, 2024)

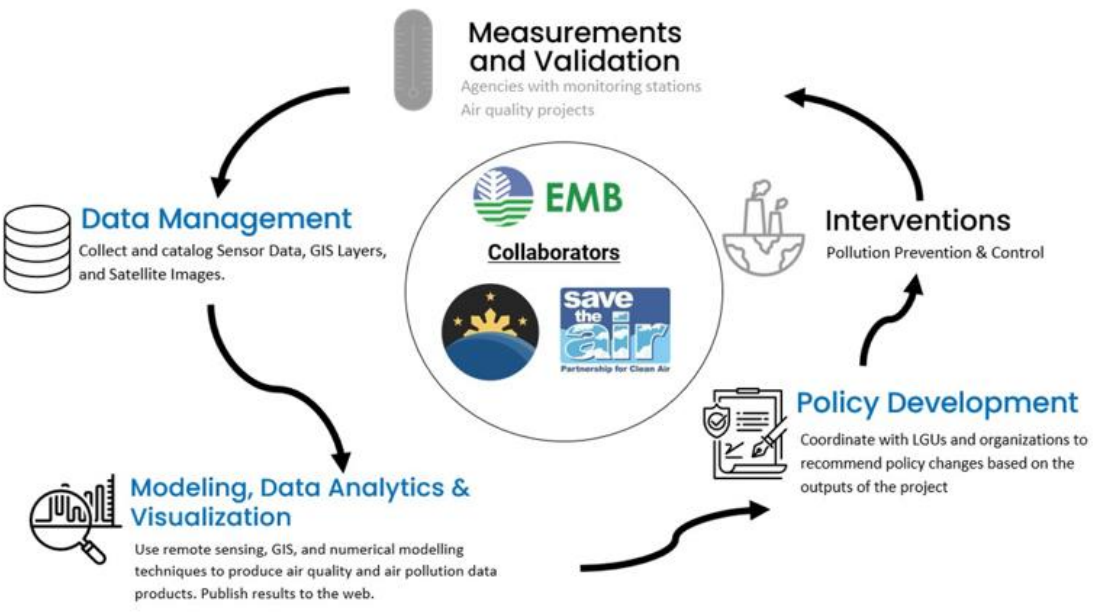

Figure 2. Project AiRMoVE Framework

This platform, boasting numerous data products and geophysical parameters, underscores the importance of user-friendly interfaces for data accessibility and analysis.

Locally, the DENR-EMB in the Philippines maintains a real-time dashboard accessible on their official website at https://air.emb.gov.ph/, displaying Air Quality Index (AQI) data from monitoring stations. This online resource employs a rating system to convey air quality levels, providing valuable insights for policymakers and the public.

Numerical modeling, RS, and GIS are pivotal tools in air quality monitoring and management. These technologies facilitate data integration, spatial analysis, and predictive modeling, enabling informed decision-making and trend identification over time. However, despite technological advancements, challenges persist in data interoperability and standardization. Addressing these challenges is crucial for enhancing the efficacy of air quality management strategies and ensuring the accuracy and consistency of measurements.

2. Research and Mentoring Activities

Project AiRMoVE formulated workflows and software applications based on research and inputs from the partner agencies through Focus Group Discussions (FGD), public forums, workshops, and technical training sessions. The researchers also participated in several trainings and academic conferences to enhance their understanding and skills in applying geospatial technologies for air quality mapping and monitoring and adopt methodologies for research dissemination and technology transfer.

The methodological framework, illustrated in Appendix A, features the key processes and components of the project focused on the (1) generation of the geographic databases and air quality models and the (2) development of the AiRMoVE web platform.

2.1 Development of Databases and Air Quality Models

The geographical databases developed in the project for constructing regional air quality models consist of topographic datasets, emission sources, and meteorological parameters. These datasets were derived from field measurements, satellite observations, and available records from specific agencies in the Philippines. The development of databases and air quality models involved utilizing various tools, including Google Earth Engine (GEE) for satellite imagery processing, QGIS for spatial data preparation and analysis, and AERMOD for air dispersion modeling.

A JavaScript-based script was developed to download relevant datasets using GEE, a cloud-based geospatial analysis platform for analyzing satellite imagery (Recto et al., 2023). Specific satellite products downloaded and processed using programming scripts are from sensors Moderate Resolution Imaging Spectroradiometer (MODIS), Sentinel 5P TROPOMI, Landsat, and Geostationary Environment Monitoring Spectrometer (GEMS). Aerosol Optical Depth (AOD) measurements derived from MODIS using the Multi-Angle Implementation of Atmospheric Correction (MAIAC) were utilized to estimate particulate matter through regression analysis and machine learning algorithms (Torres et al., 2023c). Ground measurements of particulate matter ($PM_{2.5}$ and PM_{10}) recorded by EMB monitoring stations were used in the modeling processes.

Other GIS-based methods applied in the research workflows include land-use regression (LUR) modeling, an approach that incorporates topographic, demographic, and environmental variables in estimating air pollutant concentration, and spatial interpolation techniques. The LUR approach, similar to multiple linear regression (MLR), utilized independent variables consisting of the road network, traffic count, Normalized Difference Vegetation Index (NDVI), population density, and elevation in the region (Torres et al., 2023b). Spatial interpolation techniques, particularly Ordinary Kriging, Simple Kriging, and Universal Kriging, were evaluated on different resolutions of $PM_{2.5}$ and PM_{10} concentration maps generated from a LUR model (Torres et al., 2023a). These spatial interpolation methods helped generate finer estimates of pollutant concentrations that can be further applied to street-level air quality monitoring and pedestrian exposure assessments.

2.2 Design and Development of the AiRMoVE Web Portal

Satellite images and available in-situ data were collected to develop the spatial database necessary for the AiRMoVE portal. These datasets were integrated using webGIS technology. The AiRMoVE webGIS platform enables students, researchers, organizations, and the general public to (1) access air quality monitoring stations, (2) explore various geographical factors influencing air quality, such as geographical parameters and proximity to emission sources, and (3) visualize research outputs, including regression models, air dispersion models, and other maps generated by the project team (Panlilio et al., 2023).

In developing the web platform, the workflows and products are divided into three main components: (1) the frontend user interface, (2) the backend and database management, and (3) automation and processing tools (Sta. Ana et al., 2023).

2.3 Trainings and Conferences

Various training sessions and conferences were conducted as part of the project's capacity-building activities, focusing on technology transfer and skill enhancement. These activities included technical workshops and trainings on remote sensing (RS) and GIS, specifically emphasizing Google Earth Engine (GEE), covering topics such as spatial data interpretation, satellite image processing, and webGIS concepts. Engagements with researchers were facilitated through collaborative training sessions and user experience testing sessions for the AiRMoVE website, allowing direct feedback from end-users on website features and functionalities. Also, forums were held to present project outputs and engage stakeholders in discussions.

The project team actively participated in various training sessions and conferences. Researchers engaged with PhilSA in its training workshop on the "Utilization and Applications of GEMS for Air Quality Monitoring in the Philippines" organized by PhilSA. They also completed the SikLab Technology Transfer course organized by UP Diliman. The team published technical papers and presented them at the 7th ISPRS Geospatial Conference in February 2023, the Asian Conference on Remote Sensing in October 2023, and the Philippine Geomatics Symposium (PhilGEOS) in December 2023. Furthermore, the team members participated in public forums

such as the Clean Air Forum organized by the EMB annually and the Air Aware event organized by the UPCARE Program. The participation of the project team in these events enabled a better understanding of the challenges and opportunities in regional and localized air quality management faced by all concerned agencies and stakeholders.

2.4 Activities with Partner Agencies

The project team actively engaged with partner agencies in various activities to facilitate knowledge exchange and collaboration. These activities encompassed focus group discussions (FGDs) with stakeholders to assess data needs, training requirements, and resource availability. Additionally, technical workshops and trainings were conducted with partner agencies to enhance their understanding of project methodologies and outputs.

The structure of capacity-building activities undertaken by the project team includes two main components. Firstly, the team conducted trainings and mentoring sessions to enhance their knowledge and skills in developing the air quality models and AiRMoVE platform. Secondly, they engaged in varied interactions with partner agencies to enable them to access and comprehend the project's datasets, methods, and outputs.

Implementation of FGDs with stakeholders involved baselining activities primarily to determine the current operations of the agencies in collecting, storing, and analyzing air quality data for ambient air quality reporting, as well as to identify the needs and challenges encountered by these agencies in enhancing their monitoring systems.

Technical workshops and trainings conducted by the project for the staff and personnel from partner agencies focused on using RS and GIS and Google Earth Engine (GEE) for air quality applications. The training sessions covered the basic concepts of remote sensing, spatial data, online databases, satellite image interpretation and processing, data visualization, and the fundamental concepts of webGIS. These topics were conveyed through lecture sessions and hands-on exercises. Technical manuals were provided to participants to guide them in the hands-on exercises using software for GIS and RS processes.

The engagement of the participants in the training sessions facilitated further collaboration and knowledge exchange. User experience testing sessions were conducted on the website to directly assess features and functionalities by end-users for visualizing air quality information. Lastly, a Stakeholders' Forum was organized to present project outputs and obtain feedback from the partner agencies, other researchers, and students.

2.5 Science Communication Initiatives

The project team also developed publicity materials in the form of infographics to emphasize the significance of addressing air pollution issues in the region and its alignment with the Sustainable Development Goals (SDGs). Project AiRMoVE initiated science communication efforts, including maintaining a Facebook page (https://www.facebook.com/projectairmove/) to distribute project updates and publications. These digital materials (shown in Appendix B) were designed to increase awareness of air pollution issues and their impact on attaining SDGs. Through these communication strategies, Project AiRMoVE aimed to bolster air quality management capacities in the Philippines, particularly in the NCR, by harnessing advanced technologies and promoting collaboration among stakeholders.

3. Project Outputs and Recommendations

Results from the research project yielded significant outputs that had substantial impacts on both EMB-NCR and PhilSA agencies. Key findings from the project were incorporated in the journal articles published in 2023 and the technical reports prepared by the team. Other major outputs include satellite data processing toolkits, training manuals (summarized in Appendix C), and the AiRMoVE Web portal. These resources facilitate data and knowledge sharing, particularly regarding utilizing remote sensing and GIS techniques for preparing and visualizing datasets essential for air quality mapping and assessment. These outputs are available through the AiRMoVE Web portal at this link: https://airmove.tcagp.upd.edu.ph/. Figure 3 shows the latest map view of the AiRMoVE Web Portal currently deployed in a UP TCAGP Data Center server. The project engaged with the UP CARE Program in sharing information on low-cost sensor measurements and in planning for the management, improvement and potential integration of the AiRMoVE Web Portal with their online platform.

Recognizing the necessity of incorporating geographical information for comprehensive air quality assessment and reporting, EMB-NCR made notable modifications to their existing online portals. EMB personnel participated in various workshops and technical training sessions, enabling them to familiarize themselves with satellite image processing, GIS, mapping of air quality parameters, and webGIS concepts. As a result, region-specific information on ambient air quality is now accessible at this site: https://air.emb.gov.ph/ambient-air-quality-monitoring/.

Capacity-building activities conducted during the project yielded tangible accomplishments. Results from FGDs with EMB personnel provided insights into their technical expertise, access to air quality-related information, and existing systems for reporting ambient air quality in the region. Training sessions, demonstrated in Figure 4, covered essential topics such as GIS and RS technologies while engagement with partners through the Clean Air Forum facilitated collaboration and knowledge exchange.

Figure 4. Technical training using RS and GIS facilitated by Project AiRMoVE on November 8 to 10, 2023 at the UP Diliman Campus in Quezon City, Philippines

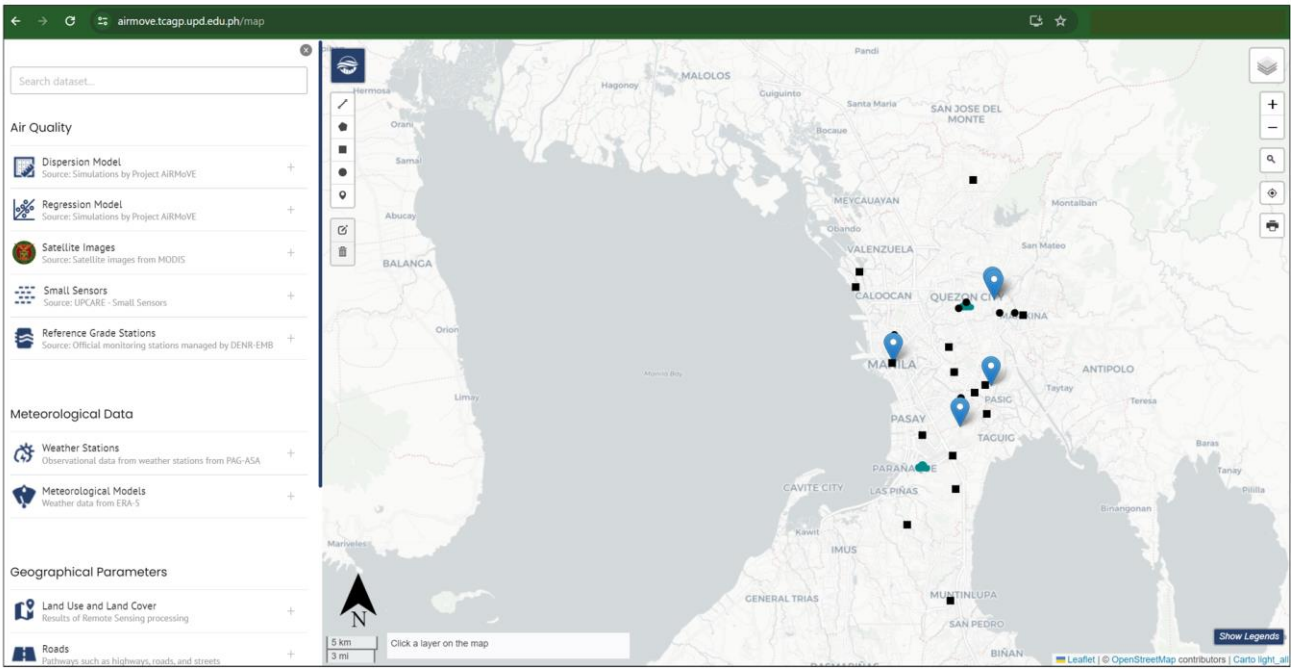

Figure 3. Map View of AiRMoVE Web Portal (URL: https://airmove.tcagp.upd.edu.ph/map)

The terminal report documented the evaluation of the effectiveness of training sessions on government agencies, feedback on capacity-building activities, challenges encountered, and opportunities for future research and methodological improvements. These insights serve as valuable inputs for refining future capacity-building initiatives and advancing air quality management efforts in the Philippines.

4. Conclusions

In conclusion, Project AiRMoVE has made significant strides in enhancing air quality management capacities in the Philippines, particularly in NCR. Through collaborative efforts with key partners EMB-NCR, PhilSA, and PCA, as well as its academic partners, the project has leveraged advanced technologies like RS and GIS to revolutionize air quality monitoring and management. Various capacity-building activities have empowered EMB personnel and other stakeholders to enhance their understanding of project methodologies and outputs, strengthening their ability to manage air quality in the region effectively.

One of the project's major accomplishments is the development of the AiRMoVE portal, which serves as a comprehensive platform for data sharing, analysis, visualization, and reporting. This portal provides access to vital resources such as satellite data processing toolkits, training manuals, and publications, facilitating knowledge dissemination and capacity building among stakeholders.

Moreover, science communication efforts, such as maintaining a Facebook page and developing publication materials, have played a crucial role in raising awareness about air pollution issues and their implications for achieving Sustainable Development Goals. By promoting collaboration and information sharing, Project AiRMoVE has paved the way for more informed decision-making and proactive measures in addressing air quality challenges.

Moving forward, it is imperative to continue fostering collaborations with partner agencies in research dissemination, technology sharing, and capacity building to further improve air quality monitoring systems. By harnessing the insights and lessons from Project AiRMoVE, we can continue to advance our understanding of air quality dynamics and develop effective strategies for mitigating air pollution in the Philippines.

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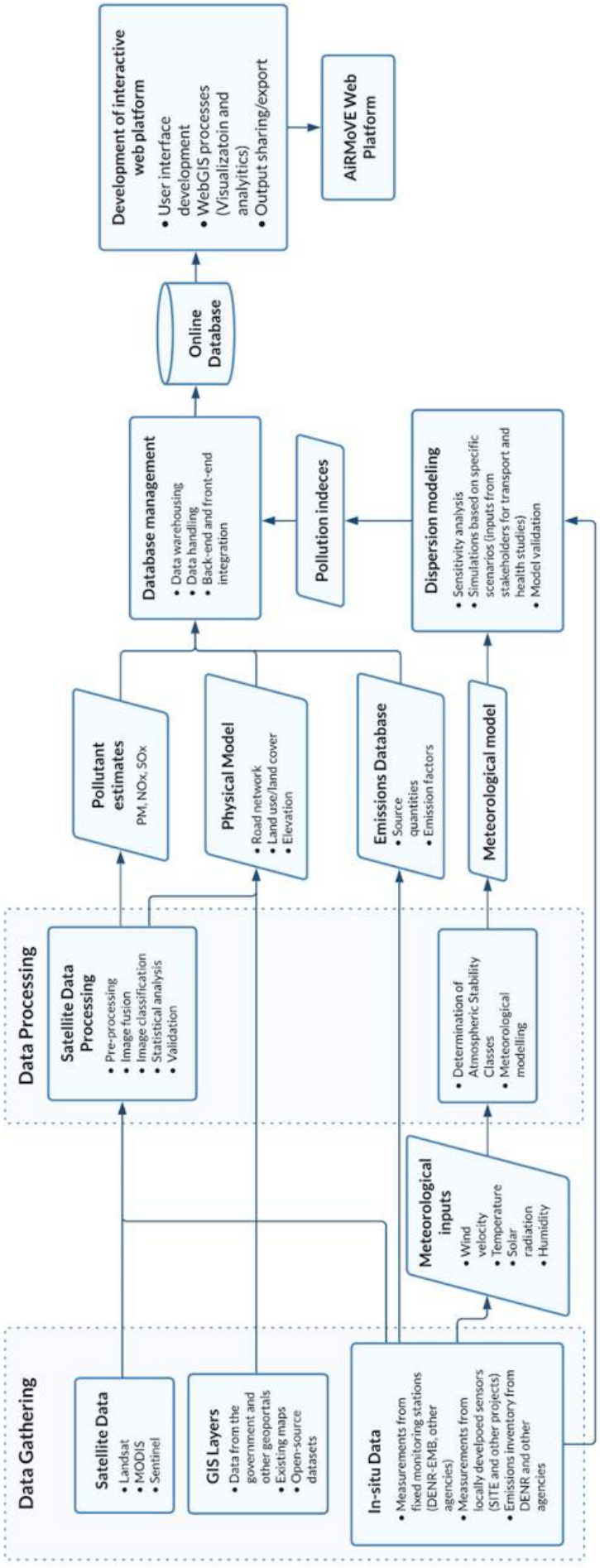
Appendix

Appendix A. Methodological Framework of Project AiRMoVE
Appendix B. Sample infographics published online by Project AiRMoVE on its social media page as part of its science communication efforts
Appendix C. List of technical manuals prepared by Project AiRMoVE

Appendix B. Sample infographics published online by Project AiRMoVE on its social media page as part of its science communication efforts



Appendix A. Methodological Framework of Project AiRMoVE

Technical Manual	Topics included
Google Earth Engine and GIS Data Portals	1. Exploring the Google Earth Engine Data Catalog Google Earth Engine and GIS Data Portals 2. Visualizing satellite images and products using GEE 3. Visualizing and downloading Sentinel satellite products using Copernicus Browser
QGIS for RS and GIS Data Processing	1. QGIS software installation and familiarization 2. Loading and Viewing Data using the Browser Panel 3. Working with QGIS plugins 4. File Conversion and Working with Attribute Tables 5. Visualizing satellite data and products 6. Extracting raster values and assign to points
Satellite Image Processing for Sentinel-5P and MODIS	1.Satellite Image Processing for Sentinel-5P NO2 and SO2 Data 2. Satellite Image Processing for MODIS Data 3. Creating a Time-series chart using GEE
Visualizing Air Quality Data	1. QGIS Base maps 2. Raster Data Visualization 3. Vector Data Visualization
Navigating the AiRMoVE WebGIS	1.Accessing the Website 2. Understanding the Map Panel 3. Understanding the Sidebar Panel Navigating the AiRMoVE WebGIS 4. Understanding the Secondary Sidebar Panel 5. Exploring the Landing Page 6. Exploring the Data Hub Page 7. Exploring the Map Page
The AiRMoVE Web Platform: Technical Manual and User Guide	1. About Project AiRMoVE 2. The AiRMoVE Web Platform 3. The Design and Development Process 4. Software: Data Processing Tools 5. Software: AiRMoVE Data Notebooks 6. Software: AiRMoVE Backend 7. Software: AiRMoVE Frontend 8. Software: AiRMoVE GeoServer 9. Deployment
Downloading ERA5 data images	1. Description of ERA5 Climate Reanalysis 2. Downloading ERA5 using GEE 3. Editing download filters for ERA5 using GEE
Correlation Analysis and Linear Regression Analysis	1. Calculation of wind speed 2. Point Sampling for data extraction 3. Exploring XLSTAT in MS Excel 4. Correlation analysis using XLSTAT 5. Linear regression using XLSTAT
Image Processing using QGIS: Kriging Interpolation	1. Definition of Kriging Interpolation 2. Converting Raster Data to Vector Points 3. Kriging interpolation in ArcMap

Appendix C. List of technical manuals prepared by Project AiRMoVE