# DEVELOPMENT OF A COMPUTATIONAL FLUID DYNAMICS MODEL FOR POLLUTANT DISPERSION IN COMPLEX TERRAIN

Inparaja Sivakunalan

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## DECLARATION

I declare that this is my own work and this Dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The supervisor should certify the Dissertation with the following declaration.

The above candidate has carried out research for the Master of Science (Major Component of Research) Dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. Mahinsasa Narayana

Signature of the Supervisor: *UOM Verified Signature* Date: 24-April-2023

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## ABSTRACT

This research investigated the issues of vehicular-emitted pollution in Kandy City, a valley-like environment experiencing severe air pollution problems due to a higher traffic volume, topographical aspect, and prevailing weather conditions. The COPERT emission model was used to calculate the total emission rates of $NO_2$, $CO$, and $PM$ in major road segments of the city. An OpenFOAM-based CFD model was developed to predict dispersion characteristics over the complex terrain, considering physical phenomena such as surface roughness, wind shear, Coriolis's effect, surface heat flux, buoyancy effect, and turbulence. The developed model was validated against experimental results to investigate its sensitivity and efficiency, and it was found to show good agreement.

The developed CFD model was then applied to simulate the dispersion of vehicular-generated air pollutants in Kandy City, considering the region's two main wind patterns NE and SW, topography, and emission rates of major road segments. The model's concentration and dispersion pattern of pollutants were found to vary with urban topography and wind pattern, with higher concentrations of pollutants observed in areas with high traffic volume and severe traffic congestion, such as the central business district and areas close to bus stands. The model was also used to investigate pollution dispersion patterns in 27 locations at the pedestrian level, with good agreement found between the model's predicted concentrations of $NO_2$ and experimental results.

Overall, this study highlights the significance of considering topography and meteorological conditions when evaluating pollution dispersion mechanisms in urban environments. The developed CFD model can be used as a promising tool for predicting pollutant transport and wind flow in the built environment, aiding in proper urban planning to reduce pollution accumulation in significant locations. This research can contribute towards effective policies and interventions to mitigate the impacts of vehicular-generated air pollution in valley cities.



**Keywords**: Atmospheric dispersion, CFD, Open FOAM, Numerical modeling, Complex terrain

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| Abbreviation | Description |
|---|---|
| $3D$ | three dimensional |
| $CO_x$ | carbon oxides |
| $Ca$ | Calcium |
| $Cr$ | Chromium |
| $Cu$ | Copper |
| $DEM$ | Digital Elevation Model |
| $Fe$ | Iron |
| $IDW$ | Inverse Distance Weighting |
| $Mn$ | Manganese |
| $NO_2$ | Nitrogen dioxide |
| $NO_x$ | nitrogen oxides |
| $Na$ | Sodium |
| $O_3$ | Ozone |
| $PAH$ | Poly-cyclic Aromatic Hydrocarbons |
| $PM$ | particulate matters |
| $PPM$ | Parts per million |
| $Pb$ | Lead |
| $R_e$ | Reynolds numbers |
| $SO_2$ | Sulfur dioxide |
| $VOC$ | volatile organic compounds |
| $Zn$ | Zinc |
| $g$ | gravitational acceleration |
| ABL | Atmosphric Boundary Layer |
| CBD | Center Business District |
| CFD | computational fluid dynamics |
| COPERT | Computer Program to Calculate Emissions from Road Transport |
| DEM | Digital Elevations Model |
| FVM | Finite Volume Method |
| GAMG | Geometric-algebraic multi-grid |
| HPC | High-Performance Computing |
| IC | Internal Combustion Engines |
| IVE | International Vehicle Emissions |

| Abbreviation | Description |
|---|---|
| KMC | Kandy Municipal Council |
| LES | Large Eddy Simulation |
| MOVES | Motor Vehicle Emission Simulator |
| MUST | mock urban setting test experiment |
| PDE | Partial Differential Equations |
| PID | photo ionization detectors |
| RANS | The Reynolds Average Naiver-Stokes Equation |
| STL | StereoLithography |
| TMC | Turning Movements Counts |
| UTM | Universal Transverse Mercator |
| WHO | World Health Organization |

## LIST OF APPENDICES