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by Sanaul Haque

Submission date: 13-Oct-2025 11:45PM (UTC+0700)
Submission ID: 2779992764
File name: Tahsin_RP_Junior_IARCO_2025_-_Muhammad_Tahsin_Abrar.pdf (263.76K)
Word count: 2120
Character count: 13209

Research Title: Artificial Intelligence (AI) Supported Decision Framework for Sustainable Urban Planning to Improve Air Quality in Dhaka City

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Research Topic	Artificial Intelligence and Environment
Date of Submission	29-09-2025

Research Aims:

The specific aim of the research is to develope and validate an Artificial Intelligence (AI) supported decision framework that integrates air quality data, urban activity patterns, and policy scenarios to guide sustainable urban planning interventions in Dhaka City.

Research Questions:

i. *How can Artificial Intelligence (AI) be incorporated into a decision-support framework to assist in the formulation of sustainable urban planning policies and interventions that effectively enhance air quality in Dhaka City?*

ii. *What combinations of data sources can be effectively fused using AI to generate reliable, high-resolution air quality information for Dhaka?*

iii. *How can AI and hybrid CTM(chemical transport models)-AI surrogate models be designed to simulate and forecast the impacts of urban planning scenarios (transportation, land-use, industrial zoning, brick-kiln relocation) on air quality in Dhaka?*

iv. *What institutional mechanisms and governance structures are needed to embed an AI-supported decision framework into Dhaka's urban planning processes to ensure long-term sustainability and accountability?*

Introduction:

Problem: Megacities experience highly heterogeneous pollution exposures driven by localized emissions (traffic, industry, residential), street-canyon effects, and meteorology. Dhaka City consistently ranks among the most polluted megacities in the world, with particulate matter ($PM_{2.5}$) levels often exceeding WHO guidelines by more than ten times. Planners need rapid scenario evaluation tools that are accurate, scalable, and interpretable.

State of the art: Machine learning and deep learning substantially improve spatiotemporal air-quality prediction, but purely data-driven models often lack physical consistency and struggle under changed emission scenarios. Hybrid strategies that couple chemical transport models (CTMs) with machine-learning (ML) surrogates produce accurate, computationally efficient forecasts suitable for policy evaluation. In addition, near-real-time integration of low-cost sensors with model outputs enhances spatial resolution for operational decision support.

Gap: Integrated frameworks that explicitly connect urban planning choices (land-use, transport infrastructure, built form) to air-quality outcomes using hybrid CTM-AI pipelines, multi-objective optimization, and explainability for stakeholders remain scarce. This project addresses that gap by delivering a full decision support system (DSS) tailored for urban planners with open software and tested policy scenarios.

Research goals: However, the reaerch goal of the reaearch is to design and validate an AI-supported, computational decision framework that enables sustainable urban planning interventions optimized for air-quality improvement in Dhaka.

Literature Review:

Air-quality context and major sources in Dhaka

Dhaka consistently ranks as one of the most polluted cities globally. Various source-apportionment and monitoring studies reveal a combination of local point and area sources (such as brick kilns and industries), mobile sources (including vehicular emissions and traffic congestion), resuspended dust, and seasonal biomass burning as the primary contributors to $PM_{2.5}$ and other pollutants in and around Dhaka. Both past and recent analyses frequently identify brick kilns and road traffic as significant contributors. Furthermore, national planning documents recognize these as key source categories for mitigation efforts[1, 2].

Observations & data streams: monitoring gaps and new data opportunities

Traditional regulatory networks in many low- and middle-income megacities including Dhaka are spatially sparse and often have reporting delays. To overcome these limitations researchers and local groups increasingly combine:

- Low-cost sensor networks and Internet of things (IoT) deployments (city-scale dense nodes) to fill spatial gaps and provide near-real-time data. Examples include recent IoT/low-cost sensor deployments and open datasets for Dhaka and Gazipur showing feasibility and value for local mapping [3].
- Satellite remote sensing (Aerosol Optical Depth, AOD from Moderate Resolution Imaging Spectroradiometer, MODIS) /Sentinel, trace gas retrievals from Sentinel-5P) as spatially continuous proxies that, when fused with ground data, help generate city-scale concentration fields.
- Mobility and activity data (traffic sensors, ride-hailing, OD matrices, mobility reports) which are critical for resolving traffic emissions and evaluating transport interventions.

Modelling approaches (CTMs, reduced-form models, and AI surrogates)

Chemical Transport Models (CTMs) provide physically based simulations linking emissions, chemistry and meteorology to concentrations; they are the methodological gold standard for scenario evaluation but are computationally expensive for many rapid scenarios runs and fine spatial scales.

Reduced-complexity models and AI surrogates: Recent literature shows two complementary trends:

- Development of reduced-complexity CTMs and parameterized solvers for urban scales to lower computational cost.
- Widespread adoption of hybrid CTM-AI approaches, where Machine Learning (ML)/ Deep Learning (DL) models are trained on CTM outputs and observations to produce fast, high-resolution surrogates that preserve much of the CTM's physical relationships while enabling rapid scenario evaluation and many-run optimization. Multiple recent reviews and applied studies report substantial speedups (often >10×) with comparable predictive accuracy for short-term forecasting and scenario emulation [4].

Decision support systems (DSS) and multi-objective optimization in urban planning

DSS architectures for urban air quality increasingly integrate (a) data ingestion pipelines, (b) modelling & surrogate prediction engines, (c) multi-objective optimizers to trade off pollution reduction, mobility, cost and equity, and (d) web-GIS visualization for stakeholders. Recent DSS examples for AQ management demonstrate how real-time data+ model outputs can be translated into daily operational advice and longer-term planning options. Research emphasizes modular, open software stacks to ensure reproducibility and uptake by municipal agencies [5].

Applications & evidence from comparable cities

Pilot applications in Beijing, London, Los Angeles and several European cities show that hybrid AI systems and DSS can:

- improve short-term forecasts and hotspot detection,
- accelerate scenario evaluation for traffic and industrial interventions, and
- provide user-friendly interfaces used by municipal practitioners. These cases illustrate the technical feasibility and potential policy utility of similar systems tailored to Dhaka's specifics (brick kiln clusters, dense informal settlements, severe seasonal variation) [6].

Gaps and research needs

The literature identifies several gaps that an AI-supported decision framework for Dhaka should address:

1. Integrated, high-resolution emission mapping for local sources (brick kilns, small industries, informal sector) that frequently lack inventories [7].
2. Robust hybrid CTM-AI surrogates tailored to city-scale policy experiments, with rigorous uncertainty quantification and transferability assessments [8].
3. Operational DSS prototypes co-designed with local agencies, including equity-aware optimization and transparent XAI outputs that planners can understand and use [9].
4. Scalable sensor fusion methodologies that assimilate low-cost network data and satellite proxies to produce reliable 1-km (or finer) concentration fields for exposure assessment [3].

Addressing these gaps will enable Dhaka-specific interventions to be tested quantitatively for air-quality and public-health benefits before costly implementation.

Research Methodology:

This research shall therefore adopt a mixed-method approach consisting of data-driven AI modelling, scenario simulation, and stakeholder-driven decision support. The framework will integrate environmental monitoring, urban planning datasets, and advanced AI techniques to build an interpretable, policy-relevant tool for Dhaka City.

Data Collection and Integration

Air Quality Data: Ground-based monitoring stations, Low-cost IoT sensor network pilot deployment, Satellite data for $PM_{2.5}$, NO_2, SO_2 proxies.

Urban and Transport Data: Road networks, land-use, zoning maps from RAJUK/DNCC/DSCC, Mobility data (traffic counts, Google mobility, ride-hailing datasets if accessible); Energy and industrial emission inventories (brick kilns, power plants, factories).

Socio-demographic Data: Population density maps (BBS), Health burden data (hospital admissions, respiratory disease prevalence).

All datasets will be pre-processed, normalized, and stored in a spatial database.

Modelling Framework

Baseline Air Quality Simulation: Run a Chemical Transport Model (CTM) such as WRF-Chem for Dhaka to simulate atmospheric processes and provide ground truth for AI training.

AI Surrogate Model Development: Train deep learning models (e.g., Conv LSTM, Graph Neural Networks, Transformers) using CTM outputs, satellite observations, and sensor data.

Explainable AI Integration: Apply XAI methods to identify key contributors (traffic, brick kilns, meteorology) to pollution and deliver interpretable outputs for planners.

Scenario Development for Urban Planning

- *Transport scenarios:* expansion of bus rapid transit (BRT), introduction of EV fleets, congestion management.
- *Industrial scenarios*: relocation/modernization of brick kilns, stricter emission controls.
- *Land-use planning*: green space expansion, mixed-use zoning, reduction of high-pollution corridors.

Each scenario will be run through the AI-CTM hybrid model to estimate:

- Air pollutant concentrations,
- Population-weighted exposure,
- Health burden reductions.

Decision Framework and Optimization

- Implement a Multi-Objective Decision-Support System (DSS): To minimize population-weighted exposure, economic cost and maximize equity.
- Build a GIS-based decision interface to visualize air quality improvements, costs, and health benefits.

Validation and Data Analysis

- Validation against independent monitoring datasets.
- Sensitivity testing for emission uncertainties and meteorological variability.
- Uncertainty quantification using Monte Carlo ensembles of AI predictions

Quantitative data from the survey will be analyzed using the following software

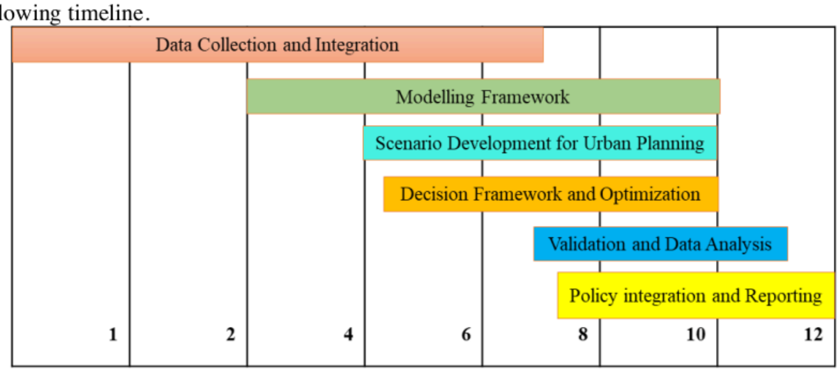
- Open-source tools: Python (TensorFlow, PyTorch, Scikit-learn), R, PostgreSQL/Post GIS for geospatial databases.
- Visualization: QGIS, ArcGIS, or web-based dashboards (Leaflet, Geo Server).

Policy integration and Reporting

This initiative can directly aligns with Bangladesh's National Air Quality Management Plan, as well as with SDG 11 (Sustainable Cities) and SDG 13 (Climate Action) and a web-based GIS dashboard can be established at the Department of Environment (DoE) or RAJUK for ongoing utilization by urban planners.

Timeline of the Research Proposal

The research project will implement over a period of twenty-four months according to the following timeline.



Research Timeline (in Months)

Research Project Feasibility

The proposed research is feasible from technical, operational, financial, and institutional perspectives. By utilizing open data, cost-effective monitoring, and hybrid AI-CTM modeling, the project effectively balances scientific rigor with practical limitations in Dhaka. The alignment with national policy frameworks guarantees institutional adoption, while pilot-scale testing facilitates scalability and sustainability. This research will adhere strictly to ethical guidelines, ensuring the confidentiality of participants and the security of data. Data collected from this research will be anonymized and securely maintained; participants will be made aware of their rights to withdraw at any time.

Conclusion

Modern literature endorses the technical viability and policy significance of an AI-assisted decision framework that integrates hybrid CTM-AI models, diverse observation streams, multi-objective optimizers, and transparent DSS interfaces. In the context of Dhaka, this framework is especially compatible with national priorities and effectively tackles ongoing data and modeling deficiencies. However, achieving success relies on thorough uncertainty quantification, meticulous design to prevent inequitable results, and robust institutional involvement to guarantee implementation.

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