Supplementary material

Table 1: City Characteristics

Data Type	Data	Periodicity	Formats	UAQM component	Source
Demographic	Population Vulnerable population School population	10 years	XML	Policy goal setting Exposure study	Census Smart City Platform
Demographic	Ward wise population density	10 years	XML	Policy goal setting Exposure study	Census Smart City platform
Economy	Projected economic growth	periodic	XML	Policy goal setting Control measures	Municipality City Master plan
Infrastructure	route length, type and location		XML	EI DSS	Infrastructure Department / Satellite
Infrastructure	Buildings		XML	EI DSS	Infrastructure Department / Satellite
	Bicycle path length and location			EI Exposure study DSS	
	Metro route length and location			EI DSS	
Mobility	Public transport route, length, frequency and location		XML/CSV	EI DSS Urban planning	Transport Department
Mobility	Parking lot location		XML	Modeling DSS	Transport Department
Infrastructure	Business areas, Residential areas, Industry areas		XML/CSV	EI Monitoring Modeling DSS	Infrastructure Department
Infrastructure	Footpath length and location		XML/CSV	EI Monitoring Modeling DSS	Infrastructure Department
Infrastructure	Place of interest (hospitals, schools, restaurants, etc		CSV/JSON	EI Monitoring, exposure assessment DSS	Infrastructure department
Mobility	Electric vehicle charging location		XML/CSV	Modeling DSS	Infrastructure Department
LULC	Green areas, open area, trees, parks, water bodies, hills	Yearly	NetCdf	Policy and goal setting, Modeling, exposure assessment	Satellite (Scientists) LANDSAT(Kantakumar et al., 2016) Garden Department
GIS**	Area and point shape files		shp	All UAQM components	Municipalities
GIS	maps		OSM/XML	All UAQM components	Openstreetmap

Climate	Local climatic zones		NetCDF	Modeling	Satellite, WUDAPT (Ching et al., 2018)
Emissions	Emission Factors		Excel	EI	CPCB
Fuel	Fuel types and distribution	Yearly / Periodic	Excel	EI Control Measures	GOI Petroleum ministry
Infrastructure	GIS Maps	Periodic	JSON	EI, Modeling, Monitoring, DSS, APP	IT department / Openstreetmap
Gap Assessment records	Monitoring, local and non-local source listing, solid waste management, pollution exposure	Periodic	Excel / Text	Goal setting, Modeling, Control Measures	Environment Department

Table 2: Monitoring and Observations#

Data type	Data	Periodicity	format	UAQM Component	source
Air Quality (in-situ) observations	PM10, PM2.5, CO2, NOx, SO2, O3, NH3, Benzene, Toulene, BC	Hourly / 15 min	XML/CSV/ Excel, Manual Hard copy	Monitoring, Modeling, DSS	CPCB MPCB SAFAR Local Municipality
Air Quality (LCS) observations	PM10, PM2.5, CO2, NOx, SO2, O3	Hourly / 15 min	SensorML, NetCDF/CF,	Monitoring, Modeling, DSS	Smart City service (IUDX)
Air Quality observations	AQI	Daily	XML/CSV	DSS	Environment Department
Air Quality Calibration	In-situ and LCS Maintenance	Periodic / Season	XML / CSV	Monitoring, Modeling, DSS	CPCB Smart City Service provider
Weather observations	Temperature, Humidity, wind speed & direction, pressure,	Hourly / 15 min	XML/CSV	Monitoring, Modeling, DSS	IMD
Satellite	NO2, O3, SO2, CO, AOD (PM10)(PM2.5)	15min	NetCDF	Monitoring Modeling	NASA Merra / Aqua,Sentinel-5P, INSAT[1]
Satellite	AOD derived fire count	15min	NetCDF	Monitoring, Modeling	FINN
Remote sensing – ground Radar	Weather parameters	15min	NetCDF	Monitoring Modeling	IMD
Social Media	Traffic update	Real time	text	Modeling	Twitter Crowd sourcing (IT department)
Social Media	Pollution status	Real time	text	Modeling, DSS	Twitter Crowd sourcing (IT department)
Social Media	Perception	Real time	text	Modeling, Health impact assessment	Twitter Crowd sourcing (IT department)
Mobile phones	Activity data, Photos	Real time	CSV / MP3 / MP4 /WAV	Modeling, DSS, APP services	Service Providers
Industry	Emission data from polluting industry	Real time (15 min)	XML/CSV	EI, Modeling, Control measures	CPCB/SPCB
Construction	dust emissions,	Real time	XML/CSV,	EI, Modeling,	Infrastructure

[1] https://worldview.earthdata.nasa.gov/
https://www.avl.class.noaa.gov/saa/products/catSearch

	Photos		JPG, MP3/MP4	Control Measures	
Transport	Road density	Real time	XML/CSV	EI, AI-Modeling DSS, Control measures	Smart City transport service
Transport	Traffic count / Congestion	Real time	CCTV image formats	EI, AI-Modeling, DSS, Control Measures	Smart city transport service
Transport	Vehicle count at Traffic junctions	Real time	CCTV image formats	EI, AI-Modeling, DSS, Control Measures	Smart city transport service
Transport	Toll data / emission zone tax data	Real time	XML/CSV	EI, Control measures	Transport department
	CCTV images				
Energy	Demand-supply	Real time	XML/CSV	EI, Modeling, DSS, Control Measures	Smart city energy service
Health	Hospital records	Daily / Extreme event	XML/CSV	Health exposure assessment, AI-modeling, Control measures	Health Department
Citizen	Feedback	Real time / intermittent	Text	Health exposure, Control measures	Environment department, IT department (social media , facebook extracts)
Citizen	Open burning images	Real time / intermittent	JPG/MP3/MP4	Control measures	Environment department
Observations (Mobile LCS)	Emission sources	Mapped to control measures	XML/CSV	Control measures, Health assessment	Scientists, Environment Department
Emissions	Emission source data	Periodic	Excel/XML/CSV	EI, Source Apportionment	Scientists / Local Environment Department
Calibration	Installation LCS and in-situ stations calibration data in laboratory setup and at location	Weekly/ random	XML/CSV	Monitoring	Vendor, Environment Department
Compliance	AQI based compliance days	Periodic	XML/CSV	Monitoring Control Measures	Environment Department
Compliance	Industry (number of industries meeting standards	Periodic	XML/CSV	Control Measures	Environment Department
Compliance	Industry (number of industries not meeting standards)	Periodic	XML / CSV	Control Measures	Environment Department

Table 3: Modeling

Data type	Data	Periodicity	format	UAQM Component	Source
Weather forecast model (Global / Regional /Urban)	Wind speed & direction, temperature, UHI, humidity, precipitation, mixing layer height, turbulence, surface and boundary layer temperature, precipitation, humidity, cloud cover, reflectivity, boundary layer depth	Now casting / Short range (1-3 days)	NetCDF /JSON	Weather model, Dispersion models, Control measures	Scientific organisations IMD
	Automatic weather station, raingauge, fluxes, Radar				IMD, ISRO
Air quality global/ regional/urban/ CFD	PM10, PM2.5, CO2, NOx, SO2, O3, NH3, Benzene, Toulene, BC,	Now casting / Short range (1-3 days) / Long range (3-10) days	NetCDF / JSON	Dispersion models Health exposure assessment DSS	Scientific organisations
Air Quality	PM10/ PM2.5 characterisation Ions, metals, carbon specific compositions, source profiles, seasonal source wise characteristics	Campaign	NetCDF / JSON	Source apportionment DSS	Scientific organisation
Air Quality Control Scenario projections	PM10, PM2.5, CO2, NOx, SO2, O3, NH3, Benzene, Toulene, BC,	Campaign / Now casting	NetCDF /JSON	DSS	Scientific organisations Local municipality SPCB
Health exposure assessment	Mortality, Morbidity, DALYs (before and after control measures) (short and long term exposure) (projected disease burden in accordance to control measures)	Campaign	NetCDF/ JSON	Policy Goal setting Modeling DSS	Health experts NGO
Emissions Inventory	Control Measures	Periodic	Excel/XML/CSV	Modeling, DSS	CPCB, SPCB, Local environment department
Emissions	Source Profiles	campaign	Excel	Modeling	Scientists
Air Quality Modeling	Control Measures*	campaign	Excel/XML/CSV	Policy	CPCB, SPCB, Local environment department

Health	Cyclist exposure / outdoor activity	Periodic	Excel/XML/CSV	Health assessment	Scientists, Health department
Air quality	Extreme event / Specific studies Model data	campaign	XML/CSV	Control Measures	Scientists
Physiographic data	USGS ASTER DEM CARTOSAT DEM DEM MODIS LULC NRSC AWiFS CARTOSAT LULC NCEP/ERA-Interm Reanalysis product		NetCDF	Weather and AQ models	Scientists

Table 4: City services

Data type	Data	Periodicity	format	UAQM Component	Source
Mobility	Multi-modal transport	Mapped to control measures	XML/CSV	Control Measures*	Smart city transport service
Health	Pollutant wise Health exposure	campaign	XML/CSV	Health Exposure	Epidemiological studies (Scientists) Hospital admissions Smart city Health services
Health	Wearable device	Mapped to control measures / campaign	XML/CSV	Control Measures, DSS	Smart city Health services
Health	Vulnerable population exposure	campaign	XML/CSV	Control Measures, DSS	Smart city health services / NGO
Emissions	Emission Factors		Excel	EI	Scientists / Local Environment Department
Governance	Emission zone surcharge collection	annual	Excel/XML/CSV	Control measures	Revenue departments, traffic department, environment department
Governance	Pollution Under Control data	Monthly	Excel/XML/CSV	Control Measures	Environment department
Calibration	Reference Grade sensors, LCS, Wearable devices, Weather models, Air Quality models, AI models, Health exposure assessment models	campaign	Excel/XML/CSV	All components	All stakeholders
Governance	Fuel Policy				

Governance	Vehicle Emission standards
	Industry Emission standards
Governance	Hospital records
Transport	Mobility data
Control Measure assessment	Implementation cost, Period for execution, benefits, DALY, Mortality rate, technical feasibility , responsibility
	Socio-economic efficacy
	Environmental status report
	RTI query and reports

Table 5: EI data categories (few examples)

Category	Data
Transport	2 wheelers, 3 wheelers, 4 wheelers, buses , taxies, taxi trajectories, bus / taxi trip data, Vehicles kilometre, travelled (VKT) as per the vehicle category
Fuel	Fuel type and quantity
Infrastructure	Road type, speed breakers, parking lots, road dust, construction, demolition, fly ash
Location	Market area, airport, station, bus stops, large hotels, open eateries, schools, hospitals, slums
Industry	Type, type of fuel used, emission category
Household	Type of residence, type of fuel used for cooking, energy source, diesel generators, domestic fuel consumption per household
Waste burning	Type of waste, stakeholder responsible for burning
Agriculture	Agriculture wind blown dust, agriculture pumps, agriculture land preparation, fertilizer
Brick kilns	Locations, type, quantity
Bakery	Number of bakeries, fuel type, consumption
Restaurants	Types, size, open eateries
Ship Vessels	Total ship entering, total ship docking,
crematorium	Type, fuel used
Power plant	Type, capacity

Table 6: Technology stack (representative)

Components	Technologies
Webserver	Nginx
Web Applications	Angular Django RestAPI
Sentry Database	PostgreSQL, MongoDB
Title Server	GeoServer
File Server (FTP Server)	FileZilla

Internal Cloud	Kubernetes, Docker
Internal local components	Python, Java
AI / ML	Tensor Flow, Keras, PyTorch, Python
Accelerators Interface	CUDA
Bid Data Analytics	Hadoop eco system, MapReduce, SPARK, OpenAir (Carslaw and Ropkins, 2012)
Map	OpenStreetMap
Visualization	NCL, VAPOR, VR software
HPC	MPI, OpenMP

Development Tasks	**Technologies**
build / release	Jenkins
Testing	Selenium, Jira
Version Control	Visual SVN
Project Management	Open Project

Table 7 # Pollutant type and its consideration in UAQM functions

Pollutants	EI	Receptor	Dispersion	AQ Monitoring	Control Scenarios	Health exposure
Criteria Pollutants						
PM10	√	√	√	√	√	√
PM2.5	√	√	√	√	√	√
NO2	√	NA	√	√	√	√
SO2	√	NA	√	√	√	√
Ozone	√	NA	√	√	√	√
CO	√	NA	√	√	√	√
Other/GHG						
NH3	√			√		
NH4	√			√		
NO3	√			√		
SO4	√			√		
VOCs	√					
Benzene	√			√		
Butadiene	√			√		
Butane	√			√		
Ethane	√			√		
Hexane	√			√		
Formaldehyde	√			√		
Total Aldehyde	√			√		
Hydrocarbons	√					
CH4 - Methane	√			√		
Non-methane HC (NMHC)				√		
Total HC				√		

Table 8: **Control Measures**

Type	**Control measures**
Domestic, Bakeries, Restaurants fuel consumption	Use of Natural Gas / LPG , Use of Electric cooking, solar cooking, LPG subsidy
	Clean cook stoves
Construction	Water spraying, cleaning after loading and unloading

Open Burning	Ban on plastic and tyre burning, optimised waste management, incentives for composting, alternative to stubble burning with incentives and technologies
Resuspended dust	Conversion of unpaved roads to paved roads, wall to wall paving, tree planting Mechanised sweeping and watering of the road
Diesel Generator	Continuous power supply
Industry	Ban of new industry in city limit, shifting of polluting industry, installation of wet scrubber, coal burning converted to natural gas, emission trading, upgrading brick clen technology, tax incentives
Vehicles	Odd / even vehicle number on road, buses and 3 Wheelers on CNG, Bus rapid transport implementation, retrofitting, ban of old vehicles, increase share of electric vehicles, installation of catalytic converter, traffic management software, designing new cycle tracks

** GIS data

Canal
City extent
Point of interest
Railways
roads
vegetation
ward
Water features
zones
Rivers
industry
Development plan

Carslaw, D.C., Ropkins, K., 2012. openair - An R package for air quality data analysis. Environ. Model. Softw. 27–28, 52–61. https://doi.org/10.1016/j.envsoft.2011.09.008

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