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Role of Green Infrastructure in Mitigating Urban Traffic Air Pollution Dispersion

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Abstract: *This research replicates urban traffic-induced air pollution dispersion using street-level spatial modeling to aid decision-making. This includes air and health evaluations. Street-level air quality decision assistance employs decision-making data. An urban base data model, geographical database-based dispersion model, and 3D GIS visualization environment are included. Dispersion model uses databases. Traffic, weather, and roadway layout affect OSPM dispersion model pollution estimates. Four pilot research sites in The Hague, Netherlands, used the framework to measure and communicate pollution levels. These areas illustrate city's main routes. Modeled 2006 NO2 and PM10 pollutants. The dispersion model included street length, width, building height, wind direction and velocity, background pollution, ambient air temperature, traffic volume, vehicle type, and speed. Cubic volumes framed buildings' planar and non-planar pollution. Vertical representation of the affected area and population may enhance pollution impact estimates. It provides crucial air quality management and assessment data to decision-makers.*

Keywords: Air pollution dispersion models, Urban traffic emissions

I. INTRODUCTION

Since European air pollution standards were implemented, local governments must take action if limits are exceeded. Local governments may be asked to offer European-standard living standards for all people. Municipalities and the public need "high-resolution" air pollution data that encompasses macro- and micro-level pollutants for a city's few monitoring sites and individual streets. Air pollution models are calibrated using observations. Setting up and maintaining a regional air monitoring network is costly.

Urban air pollution is mostly caused by road traffic (Duclaux et al., 2002; European Environment Agency, 2003; Rebolj and Sturm, 1999). Traffic air pollution distribution is crucial for air quality improvement planning. Such data helps planners optimize urban development.

Road traffic air pollution levels and affected people vary with distance from the source in a street canyon. Hot spots with pollution levels over a threshold have horizontal and vertical dimensions, which are often neglected. Because urban environmental policy standards only require monitoring and modeling of pollution levels at a specific measurement height (e.g., 3.5 m above ground), pollution below this level is ignored and upper-floor residents of high-rise buildings are not informed.

Several micro-scale air dispersion models have been developed in recent years to fill this information vacuum. Models that identify the geographical distribution of common pollutants like C02, NO2, and PM10 can estimate the horizontal and vertical variation of air pollution levels. Most dispersion models provide tabular results but don't combine them into a geographical database with street canyon contextual information for urban planners and decision makers. Linking dispersion models to GIS fixes this. GIS systems can simplify pollution dispersion modeling for local governments and the public (Rebolj and Sturm, 1999).

Many research have related dispersion models to GIS. Gualtieri et al. (1998) estimated urban traffic air pollution using GIS. The system has GIS databases, submodels, and themed maps. Submodels include transport, emissions, and dispersion.

Lim et al. (2005) developed an integrated urban air quality assessment decision support system. Innovative framework connected traffic model, emissions inventory, and dispersion model air quality sensors. In Cincinnati, Ohio, a traffic pollution model and GIS and 3D visualization were combined. Wang (2005) shows many approaches to depict pollution levels in planar and non-planar viewpoints, however the system is only practical in a location with few buildings.

This study provides spatial information about the horizontal and vertical variance of air pollution to enhance urban decision-making, suggesting that non-planar (3D) information is more relevant than planar (2D) pollution levels (used in urban environmental policies). This work integrates pollution dispersion model findings with a geographical database and presents the first 3D GIS display.

II. METHODOLOGY

This project aims to aid urban decision-making by giving horizontal and vertical variance levels of (traffic-caused) air pollution to analyze how various residents are impacted. Integrating a dispersion model's output into a geographical database with urban base data allows vertical air pollution visualization (see Figure 1).

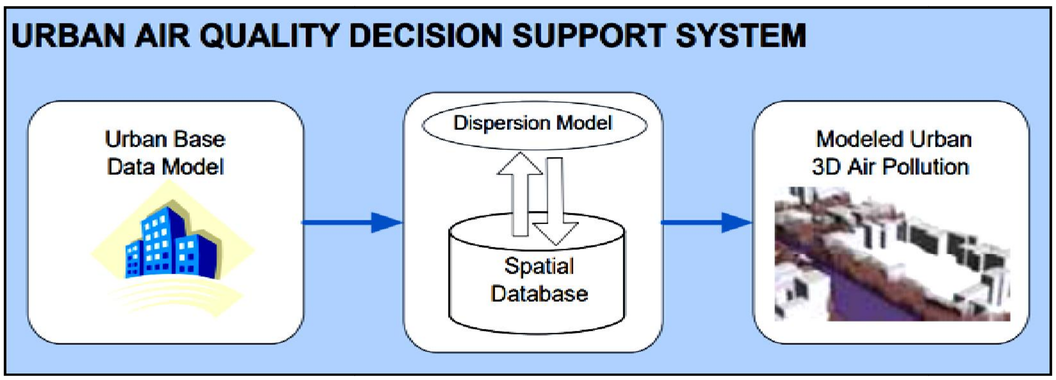

Figure 1: Conceptual scheme of system design

The article starts with a case study of traffic-induced air pollution dispersion decision making in The Hague, The Netherlands. From September to November 2007, environmental, transportation infrastructure, and city planning experts were interviewed. Municipal databases provided urban data. The Royal Dutch Meteorological Institute added data.

Several regions in The Hague have elevated levels of nitrogen dioxide (NO2) and particulate matter 10 (PM10), above the annual average of 40µg/m3 (European Commission, 1999). Street-level evaluation determined population and affected area.

A micro-scale dispersion model's tabular outputs were coupled to the geographical database to determine NO2 and PM10 levels. A 3D GIS framework was used to compare non-planar pollution levels to planar maps (Figure 1).

1. Employed Dispersion Model

This study used OSPM (Operational Street Pollution Model) dispersion. OSPM is a realistic street pollution model created by Denmark's National Environmental Research Institute's Department of Atmospheric Environment. It incorporates street canyon wind flow where the wind vortex occurs, thus street-level wind is opposite roof-level wind (Berkowicz, 2000). Figuer 2 shows street canyon wind movement. The flow condition causes street traffic pollutants to concentrate on the leeward side of buildings adjacent to the road, while buildings on the windward side are exposed to background pollution and canyon air recirculation pollution. OSPM expects windward street concentration to be lower than leeward.

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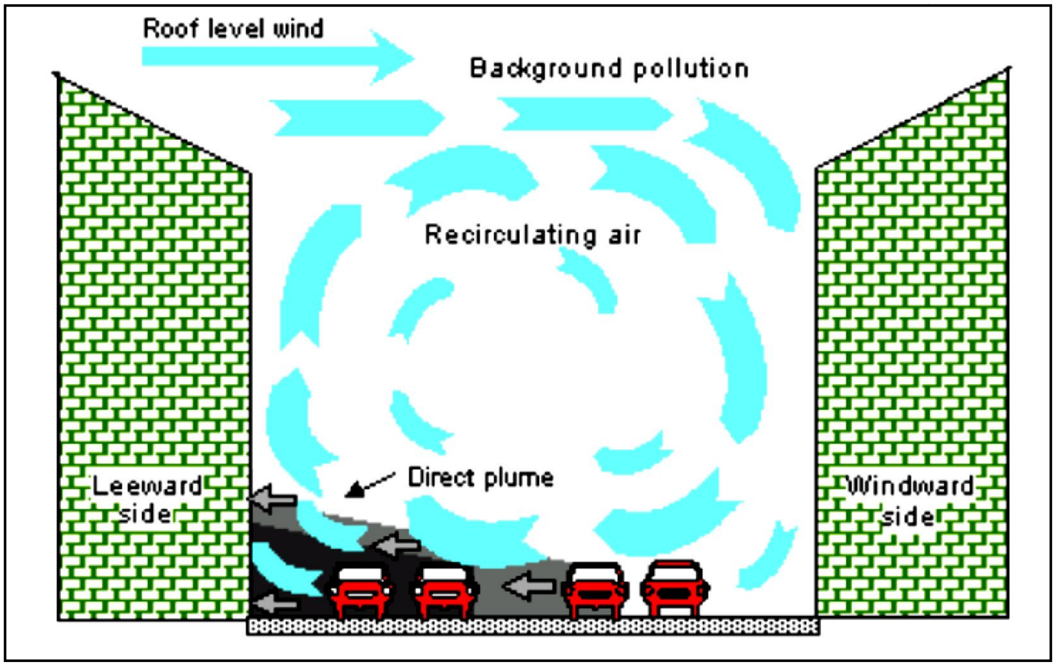


Figure 2: Wind flow in street canyon (Berkowicz 2000)

OSPM can identify ambient turbulence based on wind velocity and traffic-induced turbulence at low wind speeds (<1 m/s) (Tang and Wang, 2007). Add traffic emissions and air contaminants to calculate concentration. The direct contribution is computed using a plume dispersion model with street-level wind opposing roof-level wind (Kukkonen et al., 2000; Tang and Wang, 2007). Over the highway canyon, the model assumes linear pollutant dispersion and homogenous traffic emissions. The recirculating contribution is calculated using a box model that accounts for background pollution. Incoming flux equals traffic output, whereas outgoing flux is dominated by street top turbulence. Recirculating pollutants and portion of the emission from outside the vortex area are collected by the leeward receptor. Windward receptors get higher air recirculation contaminants. Traffic emissions from outside the recirculation zone contribute if the vortex does not fill the highway. When the wind is neutral or parallel to the road, both sides have identical concentrations.

2. Input Data

OSPM dispersion model inputs include road, building, and meteorological databases (Figure 3).Traffic data is utilized to calculate pollution levels, while street and building design and meteorological are used to estimate street canyon dispersion. In tabular form, the model outputs air pollution levels of specified contaminants at receptor locations along building facades. User-specific vertical receptor locations may be established in 1m vertical increments along building facades.

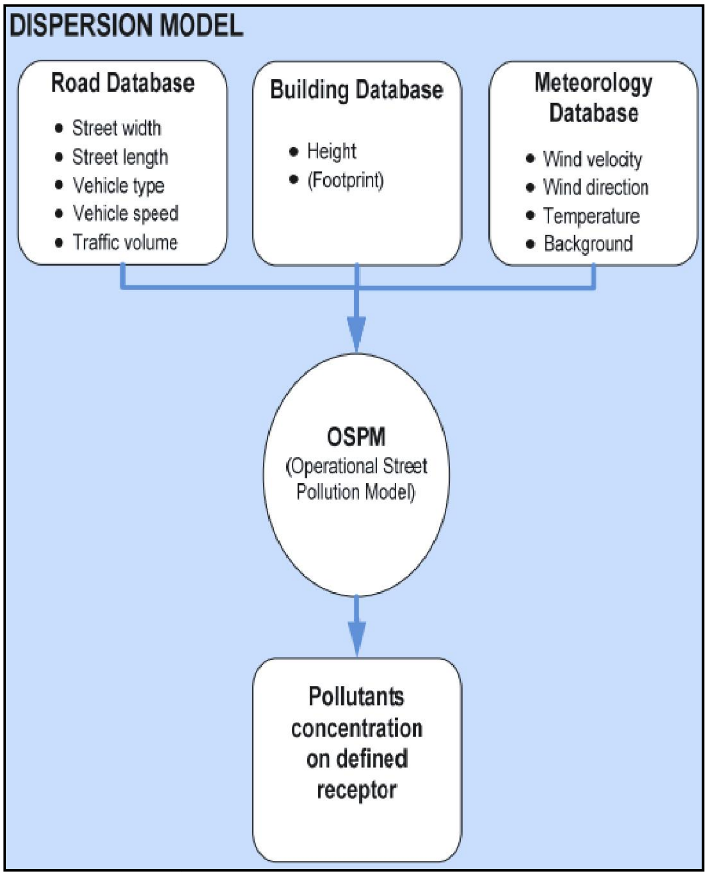


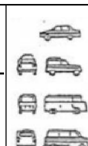
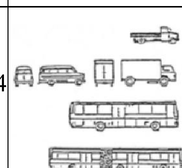
Figure 3: Components of the Dispersion Model

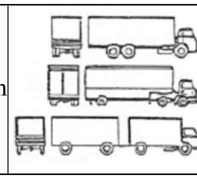
3. Road Database

Our road database has two categories: street geometry and traffic flow. Former contains roadway width and segment length; later includes vehicle type, speed, and traffic volume. Road width and length were calculated from building footprints. Light, medium, and heavy vehicles exist. Their definition is in Table 1. Vehicle speed is road segment hourly average speed. Traffic volumes show hourly vehicle counts by kind.

The Hague Municipality supplied 2006 hourly traffic volume, vehicle type, and speed statistics.

Table 1: Vehicle type categories

Light	private cars and small lorries with 4-wheel	
Middle	lorries, trucks with 2 axles and 4 back wheels, buses	

Heavy	trucks with 3 axles or more, trucks with trailer and tractors with semi-trailer.	

4. Building Database

Building database contains height and footprint. OSPM requires building height (individual and street average). The footprint was then used to create cubic structures in GIS to show vertical pollution variance. The Hague Municipality provided building footprint and height.

5. Meteorology database

OSPM requires hourly wind speed, direction, and temperature. Also needed: hourly background NO, NO2, O3, and PM10 pollution.

Rotterdam meteorological station website gave 2006 wind speed and direction. 10-meter observation station Zestienhoven. Since The Hague data was unavailable, Rotterdam data was used since they are close and have comparable weather. The NASA-sponsored Atmospheric Science Data Center provided temperature data. For availability, July 1983–June 1993 data was latest. The Netherlands National Institute for Public Health and the Environment archives provided 2006 NO, NO2, O3, and PM10 background concentrations.

6. Linking the results of the dispersion module with a spatial database

Automobile emissions, street arrangement, meteorological data, and urban background concentrations are used by OSPM to compute air pollution in front of building facades. Traffic-induced and background pollution are constant along a street axis in front of one joint building. Tabular pollutant levels at user-defined height intervals are sent to receptor sites.

Cubic structures were produced by extruding building footprints with height information to illustrate pollution. Tabular receptor point data was coupled to equally spaced vertical building sites at 1m intervals. Fig. 4a shows point dispersion. The horizontal axis points have equal pollution. Pollutant levels were interpolated. Natural neighbor interpolation was used. The interpolated result is projected on a vertically offset TIN surface in Figure 4.b. To facilitate interpolation, the building-facing vertical offset was used (Kurakula and Kuffer 2008). TIN surface and interpolation may fail if any points have equal x- and y-values. Pollution was seen on slopes and roads.

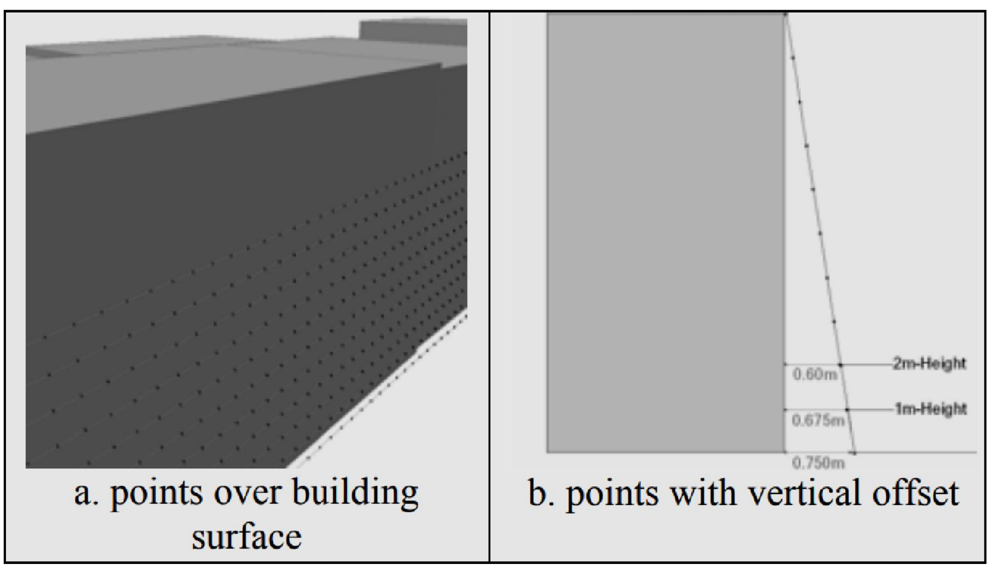


Figure 4: Even points to store pollutants concentration

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III. RESULTS OF PILOT STUDY

1. Study Area

The technique was tested in four The Hague pilot-study regions. The four principal urban road types in the city were classified to define those four regions. Figure 5 shows the four road kinds.

Category 2 includes one-story buildings on one side of the road, while

Category 3A includes roads with buildings on both sides and less than 3 times the building height.

Category 3B is a typical 'street canyon' with higher buildings on both sides of the road.

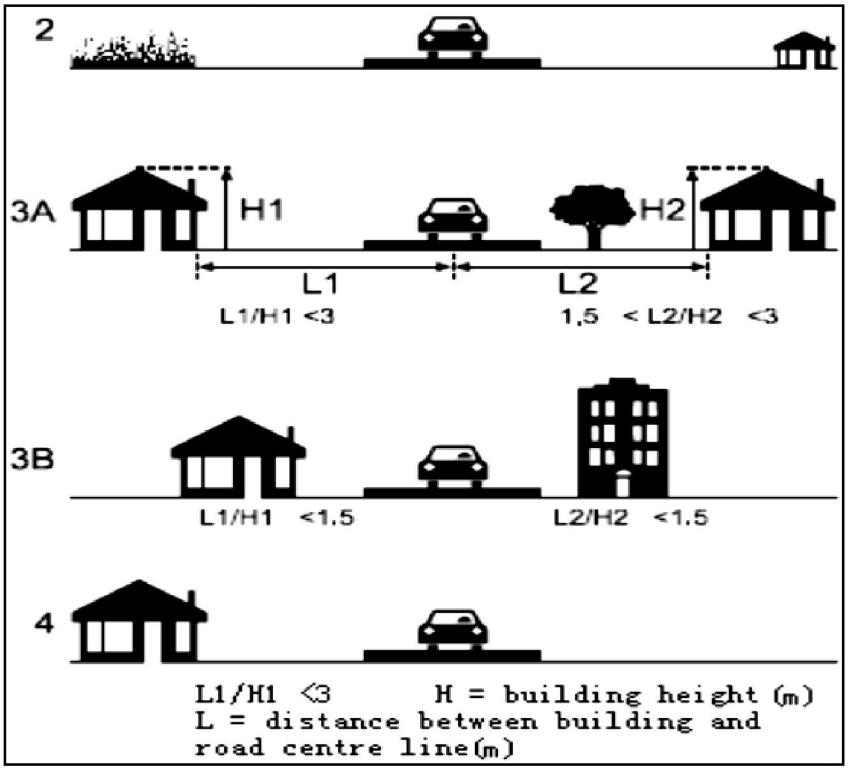

Figure 5: Road type categories (Barelds, 2007)

The profile of the four pilot-study areas is provided by the table below.

Table 2: Profile of pilot-study areas

Street name	Year of data	Surface area	L/H	Road type
Conjuction of Javastraat, Frederikstraat	2006	90 by 90m	≈1	3b
Koningskade	2006	90 by 260m	n/a	2
Conjunction of Prinsegracht, Brouwersgracht	2006	200 by 300m	≈2.5	3a
Neherkade	2006	80 by 150m	≈1	4

2. Results

Standard NO2 and PM10 measurements in The Hague and planar pollution models are done at 3.5m and 3.2m, respectively. Table 3 shows the conventional measurement height simulated values. Figure 6 shows the building plinth (measured height) tinted red under the pollution surface. As shown in Table 3, all four pilot regions surpass NO2 limit levels but all four have PM10 limit values below them. The model output seldom varies horizontally at the standard measurement height, and for PM10, Prinsegracht and Brouwersgracht, it does not vary.

Table 3: Modelled result (annual average) for NO2 at 3.5m and PM10 at 3.2m

Street name	NO2 (µg/m3)		PM10 (µg/m3)	
	Limit value	Modelled Value	Limit value	Modelled value
Conjuction of Javastraat, Frederikstraat	40	60.45 - 60.50	40	33.72-33.73
Koningskade		60.58-60.63		33.72-33.73
Conjunction of Prinsegracht, Brouwersgracht		60.37-60.54		33.73
Neherkade		60.90-60.99		33.72-33.73

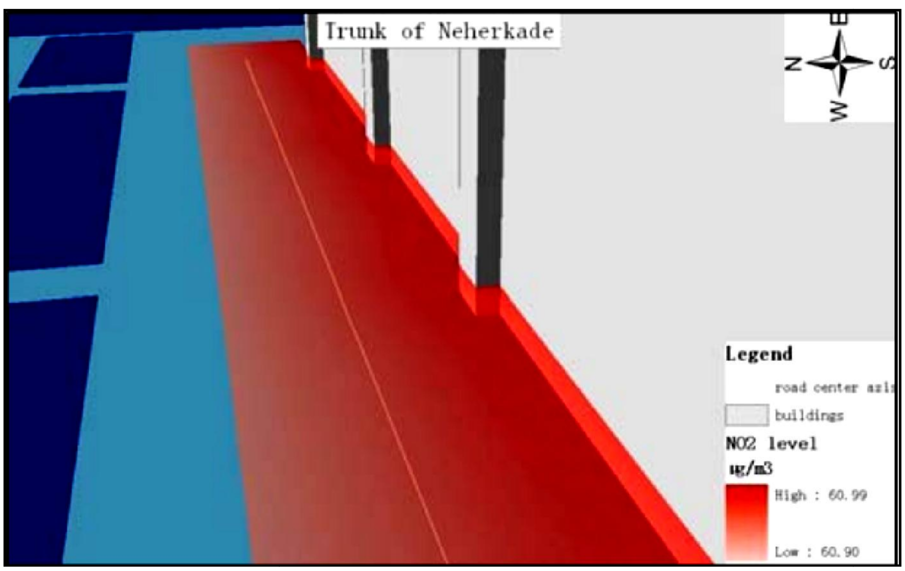

Figure 6: Observation height of NO_2

Even though horizontal variation is small, Figure 7 indicates pollution hot areas. The chosen color ramp shows the greatest pollution levels clearly. This information may help determine where air quality improvements are required, such as air movement.

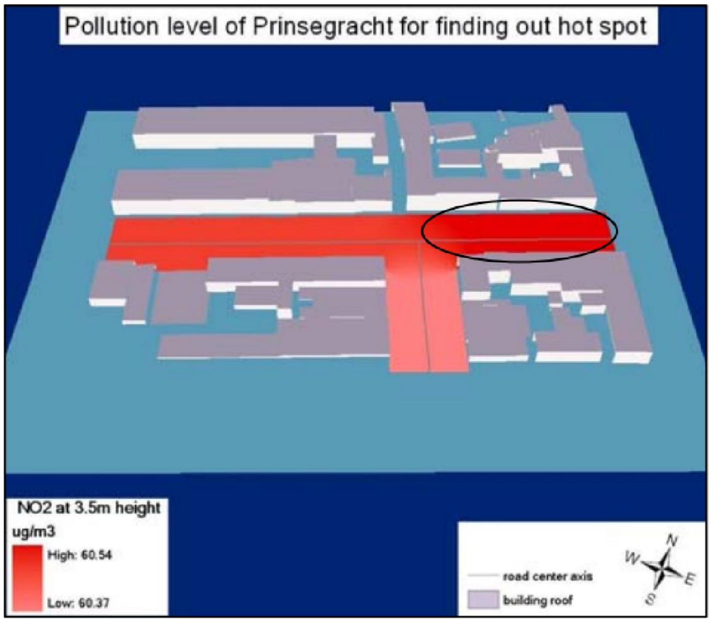

Figure 7: Pollution hot spot

In non-planar images, vertical pollution fluctuations are visible. Vertical pollution levels are shown in 3D by rasterizing interpolated pollution onto the sloping building façade. In Figure 8, pollution surrounding the building plinth has grown. Despite Figure 8, upper levels have less pollution. Upper floors break limitations.

In theory, pollution isolines might notify of exceeding limits. One can calculate the height (H) where pollution exceeds the limit. Street-level polluted sites and building facades with values over the limit may be recognized. Get the raster cell count underneath an isoline.

raster cell size × N = polluted area.

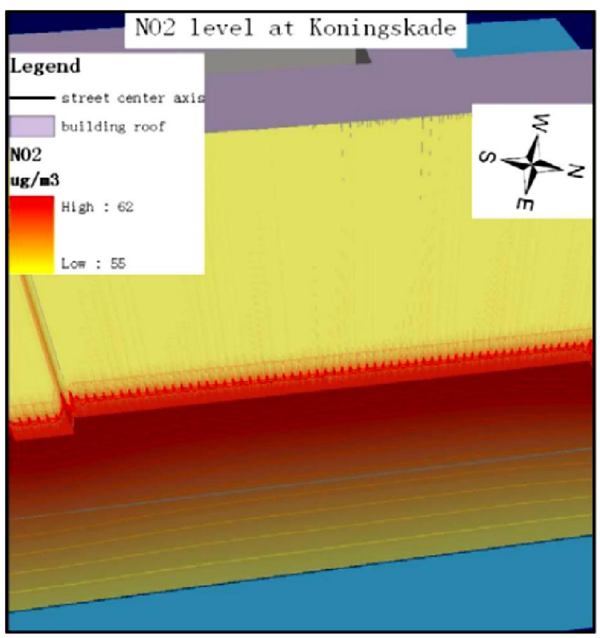

Figure 8: Pollution isoline

A warning line that shows pollution restrictions are exceeded may also be used to estimate affected floors and occupants. No such event was witnessed at pilot research sites as NO2 exceeds the limit everywhere. Figure 9 depicts warning line implementation. Using rectified traffic data from the case study site, a 60m skyscraper typical of Asian mega cities shows vertical pollution variation. OSPM output was linked to the spatial database again to show a 17m warning line. FIGURE 9 illustrates the area below and above the barrier. Such information might be used to design new buildings with lower levels and air circulation systems that bring fresh air from the top floors if lower floors are polluted.

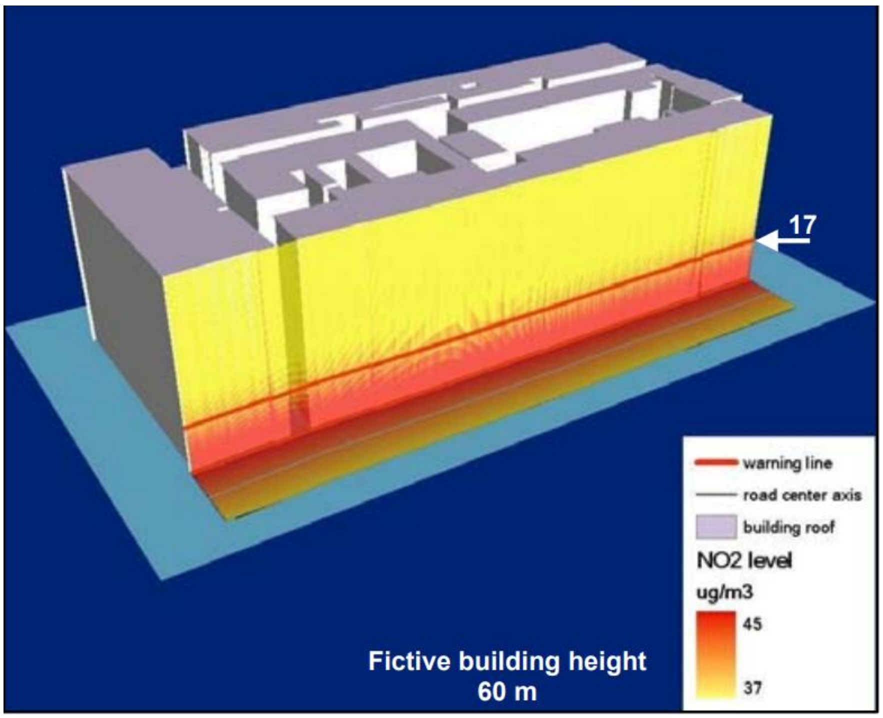

Figure 9: Pollution warning line

IV. CONCLUSIONS

OSPM pollution levels may be shown in 3D GIS using a geographical database. Planar and non-planar pollution mapping was possible in 3D GIS. Planar representation makes the cubic construction model easier to understand. Color ramps identify polluted hotspots. Non-planar street surface and building facade pollution visualization reveals volatility. Building facades and streets may form pollution isolines. Overpolluted isolines may warn. Pollution warning lines may help assess key spots. It can estimate how many people are impacted in a building, street, or neighborhood. These models simplify new building and area development design decisions, including traffic circulation planning. Urban micro air circulation bottlenecks near pollution hotspots are obvious. Analysis of future air pollution and high-rise building ventilation alternatives are possible.

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