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Application of a numerical software to investigate the urban traffic-related air pollution in the real case of Cagliari (Italy): results and improvement through Urban Microclimate Design mitigation strategies

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1. Introduction

The World Health Organization identifies air pollution as the primary global environmental risk factor (WHO, 2021). In 2016, 91% of the world's population breathed polluted air, causing 4.2 million deaths worldwide (WHO, 2018). Urban outdoor air pollution is primarily generated by traffic-related emissions (Khreis et al., 2020).

Traffic-Related Air Pollutants (TRAPs) originate from motorized vehicles through exhaust and non-exhaust mechanisms (e.g., suspended dust, brake and tire wear) and interact with background pollutants from other sources (e.g., industry or heating). Their dispersion or accumulation depends on meteorology, topography, and urban morphology, and human exposure can lead to health issues, including premature mortality (Khreis, 2020). Consequently, urban TRAPs modelling has gained increasing attention, requiring appropriate tools to support long-term air pollution mitigation strategies and regulations. For these reasons, this study presents ENVI-met[®] (Bruse & Fleer, 1998) numerical simulation results, with three main targets: 1) to assess its capability to reproduce TRAP concentrations and meteorological parameters measured by the ARPAS (Agenzia Regionale per la Protezione dell'Ambiente della Sardegna) CENCA1 monitoring station in the highly congested via Cadello area (Cagliari, Italy), starting from traffic flow and fleet data, together with meteorological data from the meteorological station of ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) monitoring network; 2) to analyze the spatiotemporal distribution of TRAPs, in relation to urban morphology and the CENCA1 monitoring station location; 3) to evaluate geometrical and green-based mitigation strategies (specifically barriers and edges), by simulating their impact on the TRAP concentration reduction at pedestrian level.

2. Materials and Methods

The investigation area (Fig. 1) was chosen around Via Cadello, a main access road to Cagliari (Sardinia's capital, Italy), near the ARPAS CENCA1 station, which includes both air quality and meteorological instruments. The simulated zone is 426m-wide, 720m-long and 90m-high, the height being twice the highest elevation reached by a building. A digital 3D model was developed using 2m×2m×2m cells, incorporating terrain elevation, soil and building materials, and vegetation. Modelling and simulations were carried out using ENVI-met[®], a software widely adopted for urban microclimate

studies (Fabbri and Costanzo, 2020) but less commonly applied to pollutant dispersion. The simulations covered 24 hours on the 21/12/2021, selected for low wind conditions and for measured data availability. ARPAS provided CENCA1 pollutant concentrations and meteorological parameters for validation purposes, along with background concentrations from the CENMO1 station; ISPRA supplied meteorological input data from the harbor station; ITS S.c.a.r.l provided traffic flow and fleet composition, measured by a traffic gauge (Fig. 2). Initial constant wind forcing was later replaced by hourly variable meteorological input parameters.

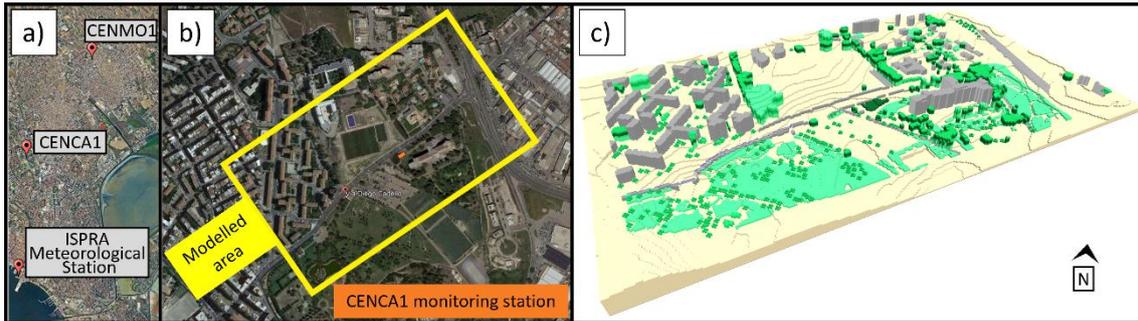


Figure 1. Geographical location and digital model: a) location of monitoring stations and b) study area (source: Google Earth), with the yellow line outlining the modelled area; c) 3D model, with terrain in light brown, buildings in grey and vegetation in green.

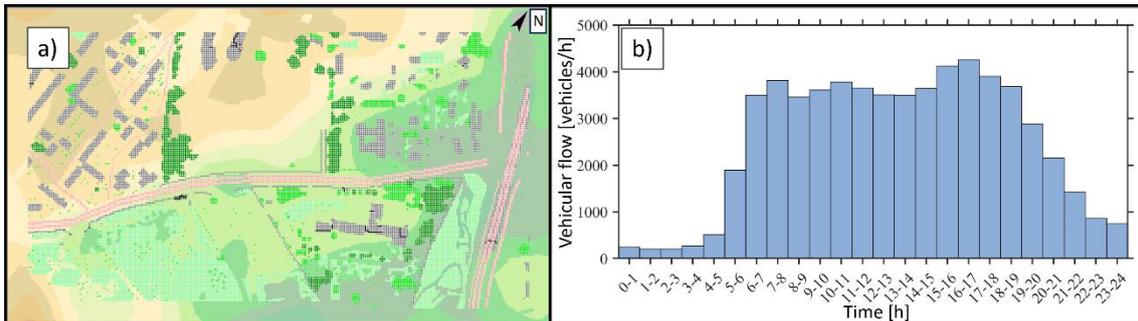


Figure 2. TRAP emissions: a) plan view of the domain with the linear pollutant sources (pink lines); b) vehicular flow in Via Cadello on the simulated day (21/12/2021).

TRAPs were released from linear sources 0.30m above ground, to approximate a vehicle's exhaust pipe. Emission factors first came from the Handbook of Emission Factors for Road Transport (HBEFA) (developed with data from Germany, Austria, Switzerland, Sweden, Norway, and France) and were successively replaced with average vehicle emission factors for road transport in Italy by ISPRA, more representative.

Several configurations were tested and refined, as initial results without fine-tuning significantly underestimated TRAP concentrations (up to 10^5 times): results shown in this work are from the final simulations.

3. Results

Fig. 3 shows the daily variation of the measured (orange) and simulated (blue) meteorological parameters (only air temperature T , relative humidity RH , and wind velocity V are shown for brevity). Measured data were taken at 2m above ground for

temperature and humidity and 10m above ground for wind velocity; simulated data, due to domain discretization, at 3m and 11m, respectively. Simulated and measured meteorological parameters show a remarkable agreement, especially considering that the input data came from a different weather station. Both trend and magnitude are captured, though simulated peaks occur 2-3 hours earlier and are slightly underestimated.

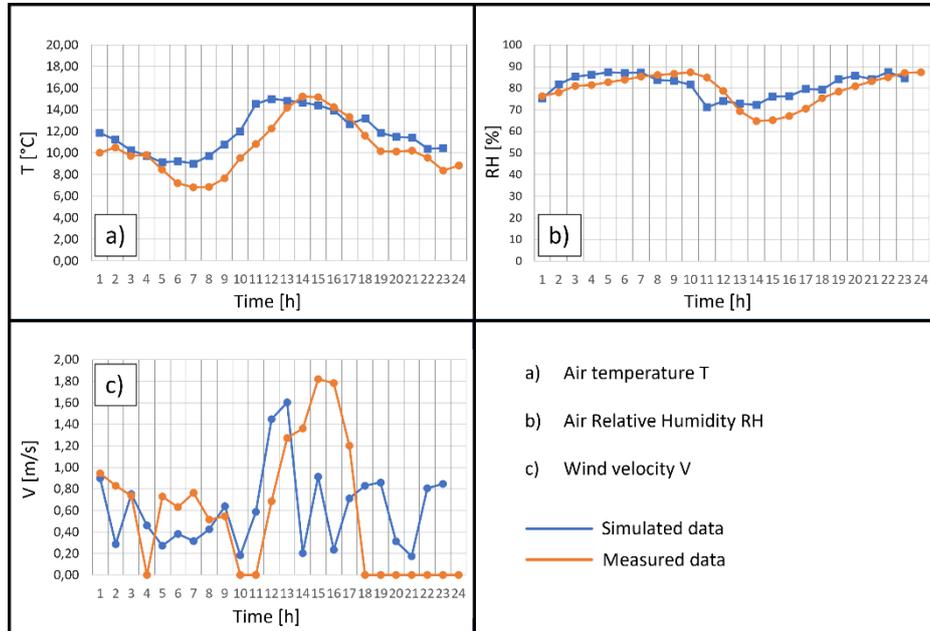


Figure 3. Comparison of simulated and measured meteorological parameters.

Fig. 4 shows the daily variation of the measured (orange) and simulated (blue) TRAP concentrations (NO, NO₂ and PM₁₀ only, due to space limitations). Both measured and simulated data were taken at 3m above ground.

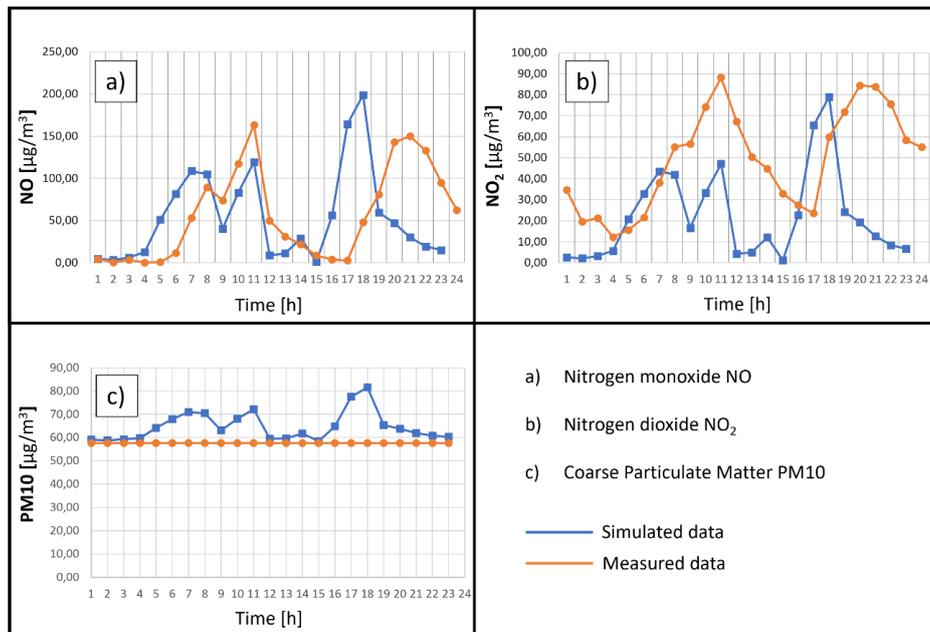


Figure 4. Comparison between simulated and measured pollutant concentrations.

Simulated and measured TRAP concentrations also show a good agreement. The NO trend is captured, with the first peak slightly underestimated and the second overestimated. The NO₂ trend is also reproduced, though values tend to be underestimated. For PM₁₀, only the daily average measured value is available, preventing a full trend comparison, but simulated values tend to be slightly overestimated.

Fig. 5 shows the simulated spatial distribution of NO₂ at pedestrian level (1m above ground) at 7:00-9:00 and 16:00-18:00. Other pollutants are not shown for brevity. Although the two traffic peaks occur between 7:00-8:00 and 16:00-17:00 (Fig. 2b), the maximum concentrations are recorded about two hours later. This is probably due to the urban morphology, with high walls along the main street that tend to protect nearby buildings and parks but also to limit pollutant dispersion, causing an accumulation potentially dangerous for road users, especially for pedestrians.

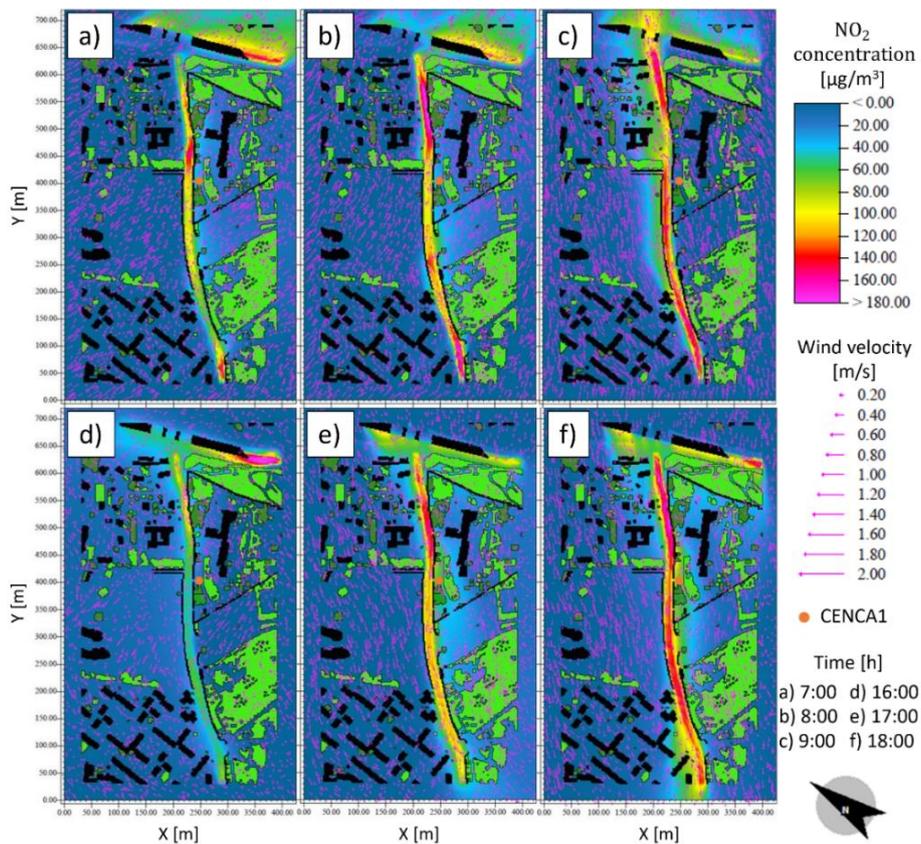


Figure 5. Spatiotemporal distribution of the NO₂.

Moreover, the areas of highest concentration do not coincide with the CENCA1 monitoring station location, implying that the values used to check compliance with legal air pollutant concentration limits are likely lower than those actually occurring, as simulated pedestrian-level concentrations tend to exceed the measured ones. The daily maximum value is $336.39 \mu\text{g}/\text{m}^3$, over four times higher the maximum at the monitoring station location (which tends to be slightly underestimated compared to measurements). In addition, during the simulated day, the hourly concentration of $200 \mu\text{g}/\text{m}^3$ is exceeded 5 times, against the 18 permitted exceedances per year prescribed by 2008/50/EC.

Two additional simulations were performed to evaluate geometrical (4 m-high plexiglass barrier) and green-based (4m-high hedge) mitigation strategies, assessing their impact on reducing TRAP concentrations at pedestrian level. Their position (shown in purple in Fig. 1c) was the same for uniformity, chosen to protect the heavily circulated pedestrian zone near the main pedestrian park entrance. Preliminary results (not reported for brevity) indicate noticeable potential benefits within the protected area for both of them, with a greater TRAP concentration reduction using the plexiglass barrier, suggesting that these mitigation strategies can enhance air quality at pedestrian level within the protected area.

4. Conclusions

In general, the results of this work are encouraging and support the validity of the adopted approach. In particular, the analysis shows good agreement between simulated and measured meteorological values and TRAP concentrations. The spatiotemporal distribution of TRAP concentrations reveals that the areas of highest concentrations do not coincide with the monitoring station location; simulated concentrations at pedestrian level tend to be higher than measured values, and peaks occur later than traffic flow peaks. Moreover, a pollutant accumulation effect by the urban environment seems to appear. This analysis can help identify the areas and times of greatest TRAP concentration and find the best placement for monitoring stations. Furthermore, preliminary results for the evaluation of geometrical barriers suggest that such mitigation strategies can help enhance the air quality breathed by pedestrians within the protected area.

These findings contribute to a better understanding of urban TRAP dynamics, to support improved regulatory recommendations for optimizing the location of air quality monitoring stations, and to assist in evaluating mitigation strategies for TRAP-related disease prevention.

Current and future works include using vehicular emission factors closer to the regional context, simulating days with mistral or sirocco winds (the other two most frequent conditions in Cagliari), investigating the sensitivity to model discretization, and extending validation to other areas.

References

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