A PRELIMINARY APPROACH TO INVESTIGATE THE DISPERSION OF TRAFFIC-RELATED POLLUTANTS IN URBAN AREAS USING A NUMERICAL SOFTWARE

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KEY POINTS

- *The present study focuses on investigating the capability of the ENVI-met® software to reproduce the concentrations of traffic-related pollutants and the meteorological parameters on a specific day*
- *The simulated temporal and spatial distribution of pollutants concentrations and meteorological parameters was promising, aligning well with measurements provided by a specific monitoring station*
- *This approach could be helpful in better understanding the traffic-related pollutants dispersion, in optimizing the location of air quality monitoring stations and in supporting urban and transport planning*

1 INTRODUCTION

According to the World Health Organization (WHO), air pollution is the primary global environmental risk factor (*WHO*, 2021). In 2016, 91% of the world's population breathed polluted air, and over half of the urban population was exposed to outdoor air pollution levels at least 2.5 times higher than the safety standards. Still in 2016, outdoor air pollution caused 4.2 million deaths worldwide (*WHO*, 2018). Outdoor air pollution in many cities worldwide is dominated by traffic-related emissions, harmful to human health and well-being (*Khreis et al.*, 2020). Traffic-Related Air Pollutants (TRAPs) are generated by motorized vehicles that emit air pollutants, including nitrogen oxides (NO_x), nitrogen dioxide (NO_2), particulate matter (PM) with a diameter less than 2.5 µm ($PM_{2.5}$) and 10 µm (PM_{10}). These pollutants can be emitted directly through the vehicle's exhaust pipe or through non-exhaust mechanisms, such as suspended dust, brake and tire wear and abrasions of the road surface (*Khreis*, 2020). Vehicles emissions, combined with background concentrations of air pollution from other sources (e.g., industry or heating), then disperse into the ambient air, influenced by meteorological parameters, such as wind speed and wind direction, terrain and urban configuration. Humans are subsequently exposed to these air pollutants, potentially causing health issues ranging from premature mortality to a wide spectrum of diseases (*Khreis*, 2020). As a consequence, identifying the right tools to support the implementation of efficient and long-term air pollution mitigation strategies is necessary.

In this work we show some preliminary results on the capability of the ENVI-met® software (*Bruse & Fleer*, 1998) to reproduce the concentrations of the TRAPs and the meteorological parameters measured by a monitoring station (CENCA1) on a specific day, to evaluate its potential for the TRAPs prediction. Moreover, we study the temporal and spatial distribution of the TRAPs in an actual urban area located in Sardinia (Italy).

2 MATERIALS AND METHODS

The investigation area (306,000 m^2) is located within the city of Cagliari and is crossed by one of the main roads, namely via Cadello, which is affected by high levels of vehicular traffic. The area contains the CENCA1 monitoring station (the orange rectangle in Fig. 1a), which includes an air quality monitoring station and a weather one, both of which managed by the ARPAS (Agenzia Regionale per la Protezione dell'Ambiente della Sardegna) air quality monitoring network. The area was modeled using ENVI-met® in a three-dimensional grid with 213 x 360 x 45 cells of 2 m x 2 m x 2 m (Fig. 1b). The vertical extent of the model was considered twice the highest elevation reached by a building. The entire model contains terrain elevation information through the adoption of Digital Elevation Models (DEMs). The simulation covers a 24-hour period on December 16, 2020: this day was chosen according to the meteorological parameters provided by the ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) Cagliari tide gauge station, located within the harbor area approximately 3,000 m South of the study area. On that day, anemometric conditions were: low average wind speed (1.24 m/s) and a prevailing direction from the South (181° N). These data were chosen as boundary conditions for the simulations, to test the capability of the software to reproduce the weather conditions in an area starting from the available data in a nearby location; in particular, the average wind speed and direction remain constant, while air temperature and relative humidity followed an hourly time series.

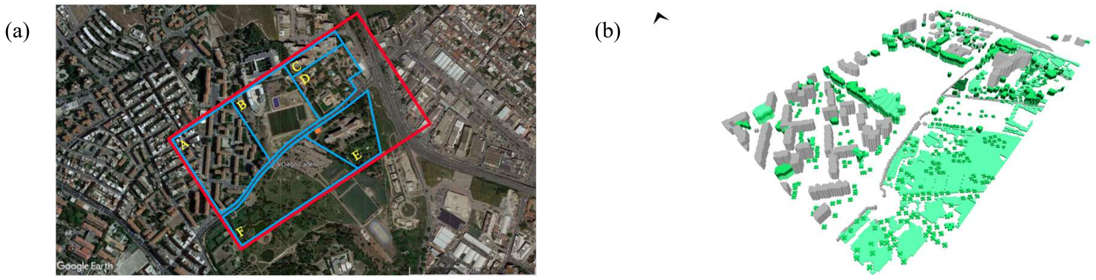

Figure 1. The panel (a) shows the study area (Source Google Earth): the red line outlines the simulated area and the blue line identifies specific zones with homogeneous characteristics; the CENCA1 monitoring station is indicated by an orange rectangle. The panel (b) displays the three-dimensional representation of the model: buildings (in gray) and vegetation (shades of green) can be observed.

The modeling of the TRAPs (nitrogen monoxide NO, nitrogen dioxide NO_2 and particulate matter $PM_{2.5}$ and PM_{10}) depends on available traffic information (traffic distribution and composition) for the studied day and on emission factors assumed for each vehicle category. Initially, traffic information was provided by the Transport Section of the DICAAR - Cagliari, while the emission factors came from the Handbook of Emission Factors for Road Transport (HBEFA), developed with the contributions of Germany, Austria, Switzerland, Sweden, Norway and France vehicle fleets. With these considerations, a point pollutant source was modeled for each road within the study area, tailored to traffic characteristics, and successively arranged along the center of each road. The sources were located at 0.30 m above the ground level to emulate the average height of the exhaust pipe. Background concentrations of air pollution measured by the CENMO1 monitoring station, also part of the air quality monitoring network managed by the ARPAS, were also considered.

Throughout this study, multiple simulations were led with different configurations. The use of multiple simulations was necessary to refine the modeling and the configuration process. In particular, traffic information was integrated with studies conducted by the ITS Città Metropolitana S.c.ar.l company (which justified a twofold increase in the Daily Traffic Value on the main road via Cadello) and the emission factors were replaced with average emission factors for road transport in Italy, provided by the ISPRA (which are generally higher than the ones from the HBEFA). Furthermore, the point pollutant source was replaced with a linear one and then successively arranged along each lane of every road, linking the traffic-related emissions to the length of the road and the number of lanes. Without this fine-tuning, first simulation results highlighted a significant underestimation of pollutants concentration values, which were several orders of magnitude (up to 10^5 times) lower than those actually measured by the CENCA1 station. For this reason and for the sake of conciseness, in the next section, the focus will be on the last simulation results.

3 RESULTS

3.1 Temporal distribution of meteorological parameters

Fig. 2a shows the daily distribution of the measured wind direction (solid red line), with its average (red dashed line) and the average of the simulated values (dashed blue line); data are taken at the height of the meteorological station (10 m above the ground level). The simulated wind direction oscillations are very small, due to the constant forcing conditions imposed: as already stated, one of the targets of this work is evaluating the capability of the software to predict the TRAPs even with raw input data. Simulated and measured average wind direction show a remarkable agreement, in particular taking in mind that the input data for the simulations come from a different weather station. Fig. 2b shows that the agreement between measured and simulated wind speed is very good. At 1 p.m., the wind speed measured by the weather station reaches its maximum value, as well as the air temperature, showed in Fig. 2c: this can be explained with the wind direction which, as above shown, comes roughly from the South, and it is consequently a warm wind in the chosen location. Fig. 2c shows that the simulated air temperature trend is qualitatively similar to the measured one, even if its oscillations are underestimated. Similar considerations can be drawn for the relative humidity (Fig. 2d), even if in this case the simulated values tend to be always lower and earlier than the measured ones. In summary, the results of the simulated meteorological parameters show a good correspondence with the ones measured by the weather station associated with CENCA1.

3.2 Temporal distribution of pollutants concentration

On Fig. 2e – 2h, the comparison between measured (red) and simulated (blue) TRAPs (NO_2, $PM_{2.5}$, PM_{10} and NO) concentration is shown; simulated values are taken at the height of the monitoring station (3 m above the ground). The simulated pollutant concentration shows a good quantitative correspondence with the measured concentration (Fig. 2e, f, g), with the exception of NO (Fig. 2h). The measured concentrations appear mostly higher than those simulated, except for PM_{10} (Fig. 2g); moreover, ARPAS provides only a daily average PM_{10} concentration, so an assessment on the hourly distribution of the compared time series is not possible.

The time series of the simulated concentrations show the projection of a single peak, shifted a few hours forward from the first peak of the time series of measured concentrations; after the peak, the values of the simulated concentrations decrease, but much more slowly than the measured ones do. Although the typical concentration peaks, observed in the time series of measured concentrations at times when vehicular traffic activity is commonly most intense, were not reproduce by the simulations, the results achieved in this study are encouraging for a potential use of the software as a forecasting tool.

In particular, ongoing tests involving a temporal varying forcing have shown results much closer to the measured values, even for the NO concentration; this serves as a promising anticipation of the upcoming stages of this work.

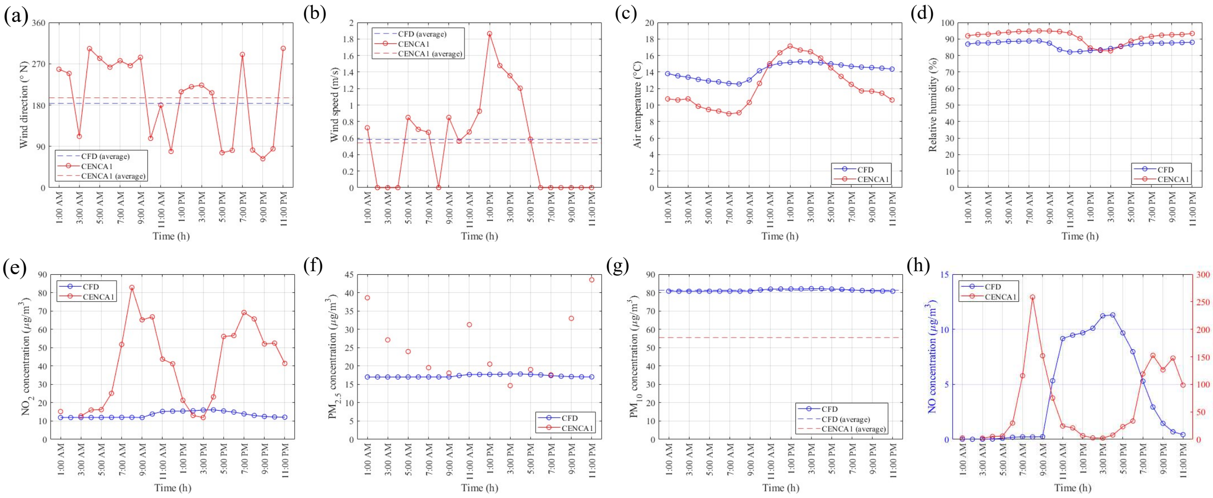

Figure 2. Panels a-d: simulated (blue) and measured (red) wind direction (a) and speed (b), air temperature (c), relative humidity (d); panels e-h: temporal distribution of simulated (blue) and measured (red) concentrations of NO_2 (e), $PM_{2.5}$ (f), PM_{10} (g), NO (h).

3.3 Spatial distribution of meteorological parameters and pollutant concentration

The simulated spatial distribution of wind direction and speed (Fig. 3a) and NO_2 concentration (Fig. 3b), at 7 a.m. and at 1 m above the ground level (pedestrian level) are here discussed. 7 a.m. corresponds to the moment when NO_2 concentration reaches its peak within the study area. For brevity, the other pollutants are not shown. Fig. 3b shows air pollution hotspots located within the study area, with concentration values much higher than both those measured by the CENCA1 at 3 m above the ground level and the limit for the protection of human health prescribed by the Italian Legislative Decree 155/2010 of 40 $\mu g/m^3$ (on a yearly average). It is noteworthy that the highest concentration regions are not coincident with the monitoring station position, so the highest pollutant concentration measured by the monitoring station itself does not highlight the highest pollution values experienced by people in the nearby area: this kind of spatial analysis could consequently help in defining the best position for monitoring stations.

In summary, the results of this work are encouraging (and help to confirm the validity of the approach adopted so far). As above stated, this work could be improved introducing a temporal varying forcing and, most importantly, a vehicular emission more close to the one of the specific case (not available when the simulations were performed). Further present and future developments concern the evaluation of the software performance when the model is subjected to different conditions of wind speed and direction (Mistral and Sirocco). Eventually, other areas could be modeled to verify the robustness of the results and their potential sensitivity to the location.

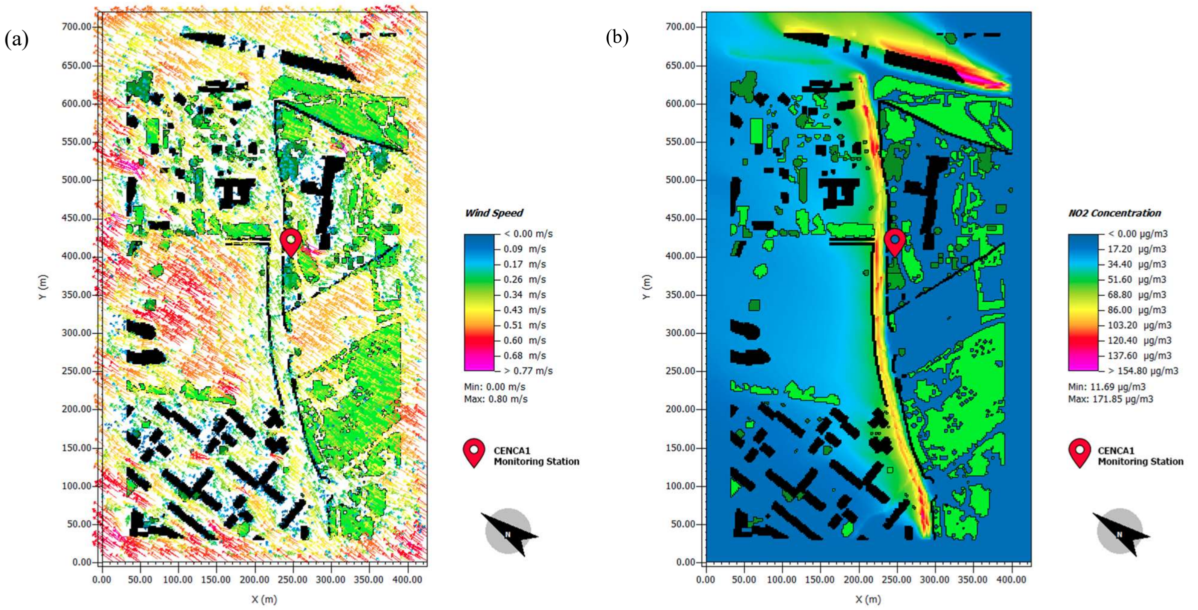

Figure 3. The panel (a) shows the wind direction (vectors) and intensity (colors) field and the panel (b) displays NO_2 concentration field, both at 7 a.m. on December 16, 2020 and at 1 m above the ground level. Buildings are in black and vegetation in green.

4 CONCLUSIONS

The main target of this study was to investigate, through numerical simulations, the ability of the ENVI-met® software to reproduce the concentrations of the traffic-related pollutants and the meteorological parameters measured by a specific monitoring station on a particular day, in order to evaluate its use in the forecasting field. The other objective was to study the pollutants dispersion and their spatial and temporal distribution in an urban area. The whole study was done in the specific case of Cagliari (Sardinia, Italy). Various simulations were carried out, gradually refining the simulations parameters to better match the measured data.

The results show a good correspondence with the measurements of atmospheric parameters and are promising for the concentration of pollutants. The spatial distribution of pollutant concentration has shown that the areas of greatest concentration of pollutants are far from the air quality monitoring station (CENCA1) which could, therefore, measure lower concentrations than the highest one in the area and, so, not totally representative. This approach can therefore be a valuable tool to support the positioning of fixed air quality monitoring stations and the planning of possible measurement campaigns. In addition, it can support decision-makers in the evaluation of strategies to reduce pollutants concentrations and in urban and transport planning.

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