Exploring Ground-Level Ozone Distribution Across Different Land Covers in the Veneto Region, Italy

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Abstract

This study investigates ground-level ozone (O_3) distribution across different land cover classes in Veneto, Italy, from 2019 to 2022. Analysis revealed high correlations between O_3 and its precursors, such as temperature and solar radiation, across various land covers. Cropland areas exhibited the lowest O_3 levels, while built-up areas had the highest. Seasonal variations showed distinct patterns, with higher O_3 concentrations in built-up areas during warmer months and lower concentrations in tree cover areas. The findings underscore the importance of land cover characteristics in pollution management strategies.

1. Introduction

Ground-level ozone (O_3) is a crucial air pollutant with significant adverse effects on human health, ecosystems, and the environment. Unlike stratospheric ozone, which protects life on Earth from harmful ultraviolet radiation, ground-level O_3 is a major component of smog and poses various health risks, including respiratory issues, cardiovascular problems, and exacerbation of chronic conditions such as asthma (Alcock et al., 2017; Soares and Silva, 2022). The formation of ground-level O_3 is a complex photochemical process involving the reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. Understanding the distribution and concentration of ground-level O_3 across different land cover types is essential for developing effective air quality management strategies. Different land cover types, such as urban areas, agricultural fields, forests, and water bodies, can significantly influence O_3 formation and distribution due to variations in emission sources, vegetation cover, and atmospheric conditions (Huang et al., 2021). Urban areas, with higher emissions from vehicles and industrial activities, tend to have higher O_3 levels, whereas rural and forested areas may exhibit different patterns due to natural emissions and lower anthropogenic activities (Huang et al., 2018).

Few studies have investigated the relationship between land cover and air quality, highlighting the importance of spatial and temporal analyses in understanding pollution dynamics (Matci et al., 2022; Huang et al., 2021). Matci et al. (2022) observed changes in correlation between air quality and temperature over different land covers associated with COVID-19 in Turkey. Similarly, Huang et al. (2021) investigated impact of land cover on air pollution at different spatial scales in the vicinity of metropolitan areas in China.

This study investigates the patterns, correlations, and seasonal variations of ground-level O_3 concentrations over various land cover classes in Veneto, Italy, from 2019 to 2022. The Veneto region is highly polluted region with various land cover types, making it an ideal case study for exploring the spatio-temporal distribution of ground-level O_3. This region encompasses urban areas, agricultural lands, forests, and water bodies, each contributing differently to O_3. That being said, this study aims to: 1) investigate correlations between ground-level O_3 and its precursors over different land cover types; 2) investigate the frequency of high O_3 concentrations over different land cover types and seasons; 3) perform statistical analysis to determine the distribution of O_3 values within each land cover class; 4) perform temporal analysis to identify seasonal trends in O_3 concentrations and its precursors across land cover classes.

By addressing these objectives, the study intends to provide valuable insights into the spatio-temporal dynamics of ground-level O_3 and inform effective air quality management strategies tailored to different land cover types. The findings will contribute to the broader understanding of how land cover influences air pollution and help develop targeted interventions to mitigate the adverse effects of ground-level O_3.

2. Materials and Methods

2.1 Study area

The Veneto region, situated in the north-eastern Italy faces multiple air pollution challenges influenced by its geography, industrial activities, and high traffic (Pivato et al., 2023). The continental part of the Veneto region, which suffers from high ground-level O_3 pollution during the summer (Figure 1.), is mainly influenced by the flat Po valley, which runs through the region and contributes to the overall air quality of the region (Lonati and Riva, 2021). This region includes various land cover types such as urban areas, agricultural lands, forests, and water bodies.

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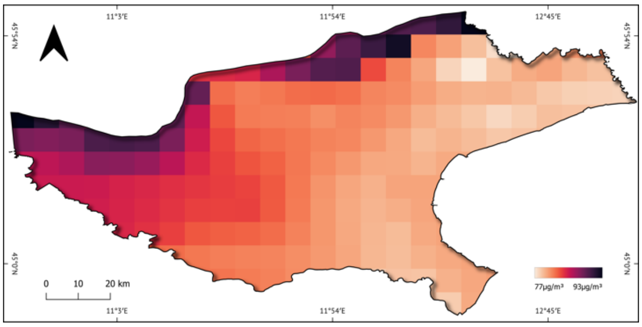


Figure 1. Mean summertime ground-level O_3 concentrations (2019-2022) over continental part of Veneto region.

2.2 Used data

Daily ground-level O_3 data used in this study are model data from January 1, 2019, to December 31, 2022. The O_3 data were estimated using a previously developed Random Forest (RF) model for the same temporal frame and study area. This RF model was validated using ground truth data from air quality stations in the Veneto region and achieved high accuracy of Pearson correlation coefficient (R) of 0.93 and a root mean square error (RMSE) of 10.88 µg/m³. The RF model uses Sentinel-5P TROPOMI (total vertical column of O_3) and ERA5 climate reanalysis (precipitation, solar radiation, temperature and windspeed) variables. These variables were selected based on their relevance to O_3 formation and dispersion processes. The model inputs were chosen to capture the climatic and atmospheric conditions influencing O_3 levels.

Land cover data are from the ESA World Cover dataset, which provides land cover information for 2020 and 2021 at a spatial resolution of 10 m. This data was resampled to 11 132 m to match the resolution of the estimated O_3 based on the majority of land cover class within the pixel. For the years 2019 and 2022, the 2020 and 2021 land cover data were used, respectively, due to the unavailability of land cover data for these years.

2.3 Data analysis

Full dataset consisted of a total of 224 664 observations for tree cover class, 37 080 for grassland, 243 243 for cropland, 4 357 for built-up areas, and 12 359 for permanent water bodies, on which four main analyses, using R programming language, were conducted:

- Correlation Analysis: Examined relationships between ground-level O_3 and its precursors (e.g., temperature, solar radiation) across different land cover classes. This analysis aimed to understand the influence of each variable on O_3 levels in various land cover types.
- Frequency Analysis: Investigated the frequency of high O_3 concentrations over different land cover types and seasons. A frequency analysis of the full O_3 dataset was conducted by dividing it into five quantile classes. This approach helped identify land cover classes with the highest and lowest accumulations of O_3 values. Additionally, a seasonal frequency analysis was performed by dividing the O_3 dataset into spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). Each seasonal dataset was further divided into five quantile classes to observe the distribution of O_3 values across different land cover classes.
- Statistical Analysis: For each season, statistical parameters such as minimum, maximum, range, mean, and median O_3 values were calculated for each land cover class. This analysis provided insights into the seasonal variations and distribution patterns of ground-level O_3 across different land cover types.
- Temporal Analysis: Identified seasonal trends in O_3 concentrations and its precursors across land cover classes using time-series plots of their mean, median, maximum, and minimum values.

3. Results

3.1 Correlation analysis

The correlation analysis revealed consistent relationships between ground-level O_3 and its precursors across different land cover classes (Table 1). Temperature showed the highest correlation over the cropland class (R = 0.83), while solar radiation exhibited a consistent high correlation, particularly over the tree cover class (R = 0.93).

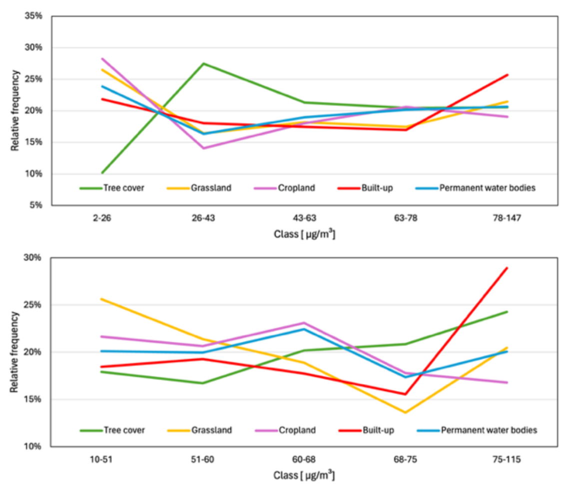
O_3 – solar radiation			**O_3 – temperature**	
Class	*R*	*R²*	*R*	*R²*
Tree cover	**0.93**	**0.86**	0.69	0.48
Grassland	0.90	0.81	0.78	0.62
Cropland	0.90	0.81	**0.83**	**0.69**
Built-up	0.89	0.80	0.77	0.59
Permanent water bodies	0.88	0.78	0.78	0.62

Table 1. Correlation between ground-level O_3 and its main precursors ($p = 0.05$).

3.2 Frequency analysis

Relative frequency analysis (Figure 2) indicated that cropland areas had the lowest ground-level O_3 concentrations, whereas built-up areas had the highest. Seasonal variations were also observed, with grassland showing the lowest O_3 concentrations in spring and tree cover in summer, with elevated levels in built-up areas. Autumn showed lower O_3 concentrations in grassland and cropland classes, with slightly higher levels in built-up and permanent water bodies. Winter showed minimal O_3 concentrations in cropland, contrasting with significantly higher levels in tree cover class.

A)
B)



C)

D)

E)

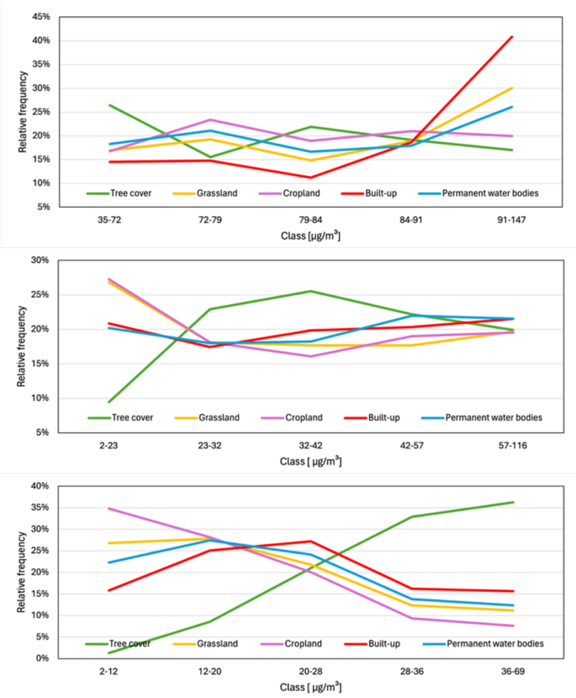


Figure 2. Distribution of ground-level O_3 concentrations across land cover classes: A) full dataset, B) spring, C) summer, D) autumn, and E) winter dataset.

3.3 Statistical analysis

Descriptive statistics (Table 2) revealed that in spring, there was minimal variation in O_3 concentrations across different land cover classes. In summer, built-up areas exhibited the highest mean and median O_3 concentrations, while tree cover areas had the lowest. During autumn, O_3 levels were relatively similar across most classes, with slightly higher values in tree cover, built-up, and permanent water bodies. In winter, all classes showed uniformly low O_3 levels, with tree cover showing the highest mean and median values.

Spring					
Class [µg/m³]	*max*	*min*	*range*	*mean*	*median*
Tree cover	**114**	16	98	**65**	**66**
Grassland	108	15	94	61	61
Cropland	105	**11**	93	61	63
Built-up	108	18	89	**65**	**66**
Permanent water bodies	104	18	86	63	64
Summer					
Class [µg/m³]	*max*	*min*	*range*	*mean*	*median*
Tree cover	**141**	**36**	105	80	81
Grassland	**146**	39	107	85	84
Cropland	138	39	99	82	81
Built-up	135	48	**87**	**89**	**88**
Permanent water bodies	137	45	92	84	82
Autumn					
Class [µg/m³]	*max*	*min*	*range*	*mean*	*median*
Tree cover	**115**	5	109	**42**	**39**
Grassland	99	4	95	38	34
Cropland	96	**3**	93	38	35
Built-up	100	5	94	**41**	**38**
Permanent water bodies	103	6	97	**41**	**38**
Winter					
Class [µg/m³]	*max*	*min*	*range*	*mean*	*median*
Tree cover	66	3	63	**33**	**33**
Grassland	61	3	58	21	19
Cropland	**68**	3	66	18	16
Built-up	60	3	57	24	22
Permanent water bodies	62	3	59	22	20

Table 2. Statistical parameters of ground-level O_3 concentrations across land cover classes.

3.4 Temporal analysis

Time-series plots of mean, median, maximum, and minimum monthly values of ground-level O_3 and its precursors showed significant seasonal trends (Figure 3-5). Mean O_3 concentrations peaked in the warmer months, especially over built-up areas, while lower concentrations were observed mostly over tree cover. During winter, tree cover areas exhibited elevated O_3 levels. Temperature plots indicated slightly higher temperatures in cropland and permanent water bodies, with consistently lower temperatures in tree cover. Solar radiation showed minimal variation between land cover classes, with slightly elevated values in cropland areas.

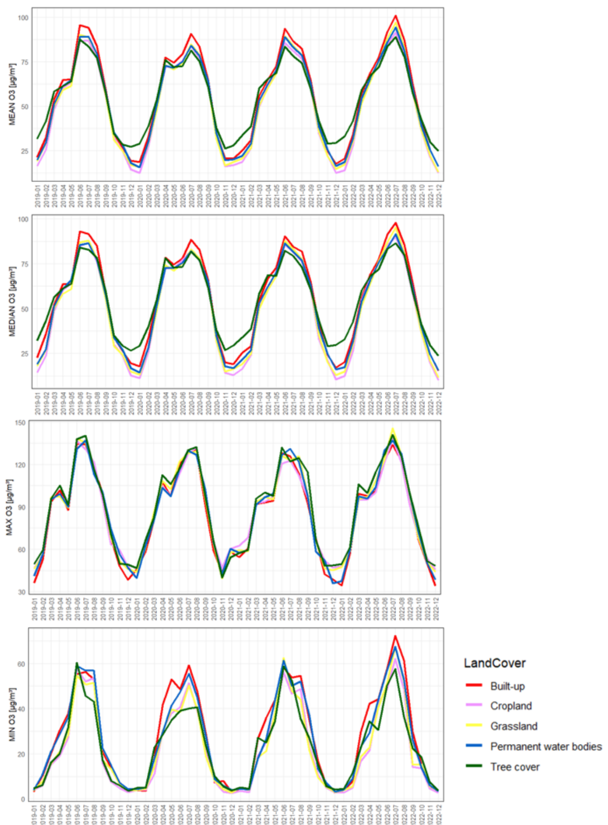


Figure 3. Time-series trend plots of ground-level O_3 over different land cover in the study area.

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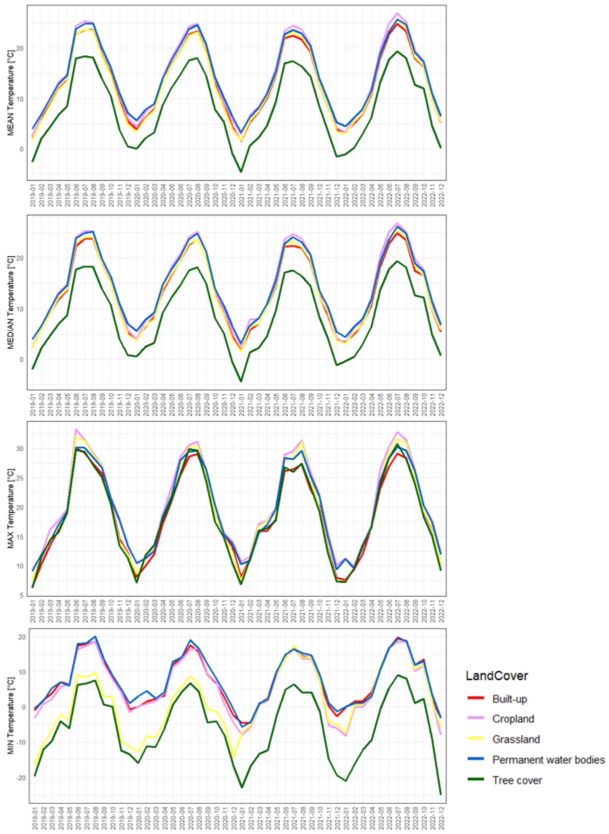

Figure 4. Time-series trend plots of temperature over different land cover in the study area.

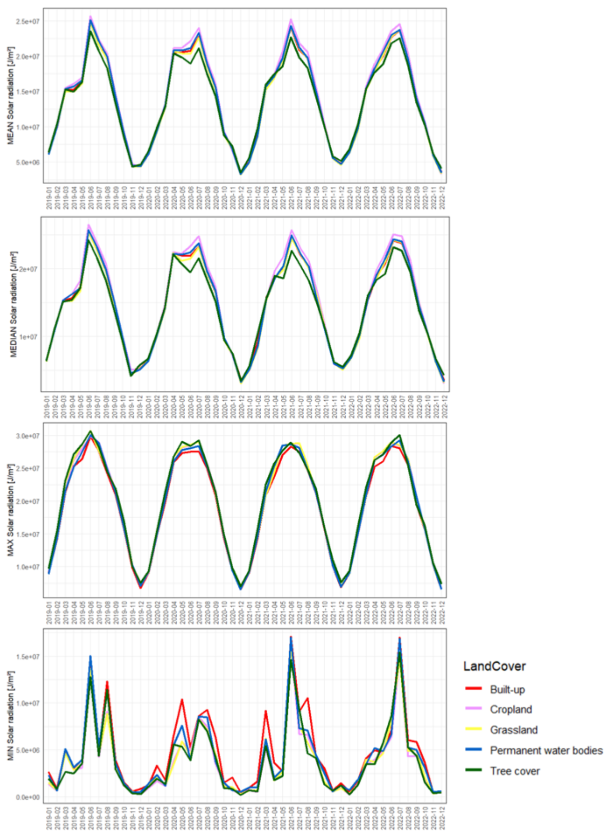

Figure 5. Time-series trend plots of solar radiation over different land cover in the study area.

4. Discussion

These findings highlight the importance of considering land cover characteristics in pollution management strategies. The observed correlations between O_3 and its precursors suggest that different land cover types influence the distribution and concentration of O_3. Built-up areas consistently showed higher O_3 levels, likely due to increased emissions and heat island effects, while tree cover areas generally had lower concentrations, potentially due to greater vegetation cover and lower emissions. Our findings on the spatio-temporal distribution of O_3 are consistent with previous studies that have highlighted the influence of land cover types on O_3 levels. For example, a study by Sicard et al. (2020) in southern Europe found that urban areas tend to have higher O_3 concentrations compared to rural and forested areas due to the higher emissions of O_3 precursors from anthropogenic sources. Similarly, our results indicate higher O_3 levels in urban and agricultural areas compared to forests and water bodies.

The correlation analysis in our study revealed significant relationships between O_3 concentrations and climatic variables such as temperature and solar radiation. This aligns with findings by Tang et al. (2019), who demonstrated that higher temperatures and increased solar radiation contribute to enhanced O_3 formation.

Our study confirmed the well-documented seasonal variation in O_3 levels, with higher concentrations observed in spring and summer compared to autumn and winter. This seasonal pattern is consistent with previous studies, such as those by Lu et al. (2019) and Paoletti et al. (2020), which attribute higher O_3 levels in warmer months to increased photochemical reactions driven by higher temperatures and solar radiation.

Despite the valuable insights provided by this study, several limitations should be acknowledged. Firstly, the study area is relatively small, which may limit the generalizability of the findings. Additionally, the spatial resolution of the data could be improved to capture more detailed variations in O_3 concentrations.

5. Conclusions

This study investigated the spatio-temporal distribution of ground-level O_3 across different land cover classes in the Veneto region, Italy, using data from 2019 to 2022. Our results revealed significant spatial and temporal patterns in O_3 distribution, with higher concentrations observed in urban and agricultural areas compared to forested regions and water bodies. The correlation analysis indicated that temperature and solar radiation are critical factors influencing O_3 levels, aligning with findings from previous studies. The seasonal analysis confirmed the well-known pattern of higher O_3 levels in spring and summer, attributed to increased photochemical reactions during these periods.

By providing a detailed spatio-temporal analysis of O_3 distribution, this research contributes to the broader body of knowledge on air quality and offers practical insights for improving environmental health and policy interventions. Future research should address the limitations of this study by expanding the study area and utilizing higher-resolution data. Furthermore, there is a lack of similar studies focusing on the correlation between ground-level O_3 and various land cover types, highlighting the need for more targeted research in this area.

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