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Contribution of Urban Forests to the Ecosystem Service of Air Quality in the City of Santo Domingo, Dominican Republic

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Abstract: A survey on pollutants that affect air quality was carried out at 27 points in the city of Santo Domingo, National District. The removal of air pollutants was estimated in relation to the city's forest cover; using the iTree Canopy software. A principal components analysis and a correlation analysis was also performed to identify the association of these variables. The results show that the average percentage of green infrastructure in the sampling points was 26%. Also, positive correlation was identified between the presence of NO_2 and SO_2 at the sampling points. It was observed that the higher the presence of forest cover, the higher the concentration of CO and the lower the presence of pollutants. Although five hot spots were defined in terms of air pollution levels in the National District, the study does not show conclusive results regarding the relationship between green infrastructure and air quality in Santo Domingo. Results show that urban planning for environmental quality requires inter-institutional coordination, permanent ecological quality monitoring, and coordinated public policies to establish adequate indicators comparable to the World Health Organization standards.

Keywords: air pollution; air quality; ecosystem services; green infrastructure

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Citation: Bonilla-Duarte, S.; González, C.C.; Rodríguez, L.C.; Jáuregui-Haza, U.J.; García-García, A. Contribution of Urban Forests to the Ecosystem Service of Air Quality in the City of Santo Domingo, Dominican Republic. *Forests* **2021**, *12*, 1249. https://doi.org/10.3390/f12091249

Academic Editor: Idalia Kasprzyk

Received: 27 July 2021
Accepted: 12 September 2021
Published: 15 September 2021

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1. Introduction

Air quality constitutes one of the environmental issues that requires the most attention in the 21st century for urban areas with high population density [1–4]. According to the World Health Organization [5], about 249 thousand premature deaths were attributable to outdoor air pollution and about 83 thousand premature deaths were attributable to air pollution due to household use of solid fuel in the Latin America and the Caribbean region in 2016.

Although air pollution can affect everyone, differences are perceived between population groups, according to geographic locations and the type of exposure they are subjected to [4–6]. Population groups residing near roads or industrial compounds, for example, are exposed to higher levels of outdoor air pollution, including people using solid fuels as a source of household energy [5,7]. In some cases, differences in exposure between population groups may be linked to inequities in developing implementing, and enforcing environmental laws, regulations, and policies [4,5].

One of the 2030 Agenda for Sustainable Development Goal is to death and disease caused by hazardous chemicals and air pollution [8]. However, according to 2018 records, the dependence on fossil fuels for transportation, industry and energy was of 80% globally [4]. Furthermore, it is expected that 66% of the world's population will be living in cities by 2050, which implies a significant growth in demand for services, like transportation, energy, and industry [8].

Population growth and the increasing expansion of cities, pose new challenges for urban planning, highlighting necessary and important elements such as green infrastructure, environmental impacts management, air quality, production of adequate information for decision making and citizen awareness [3,4,9].

The characteristics of the city of Santo Domingo, the socioeconomic peculiarities of its inhabitants, its climate, its geographic location and the changes produced in its urban configuration, make this city a compelling case for the analysis of the effects of changes in green infrastructure in urban environments. The urban development process in Santo Domingo has caused an intense transformation of the city, which has expanded horizontally and vertically, increasing the constructed area of the city at east at west, mainly with highest buildings [10]. The vehicle fleet has grown exponentially, at the same time as the population and the consequent demand for goods and services. There has been a loss of green infrastructure due to modifications in housing construction, moving from single-family to multi-family, thus, losing much of the vegetation on private property [10,11].

Green infrastructure is defined as an interconnected network of urban, peri-urban, rural and wild green spaces, which preserves and provides ecosystem services to humans [9,12]. The concept of green infrastructure comprises a strategic approach for the conservation of the landscape and its natural and cultural value components, within the framework of sustainable land management and planning initiatives, regulating the impacts generated by anthropic action [13–15].

Santo Domingo is the most populated city in Central America and the Caribbean region [10]. However, it lacks a permanent air quality monitoring system, which is a deficiency for Urban Planning and air pollution control from fixed and mobile sources. In this sense, it is necessary to assess the impact of green infrastructure on air quality in urban environments to contribute to the quality of life of new generations in the National District.

Research on vegetation cover and ecosystem services provided by green spaces has been carried out in the National District of Santo Domingo using the iTree tool, showing that the city's green infrastructure provides important ecosystem services, including the removal of pollutants [16]. Other studies establish the positive perception of the urban population on the city's green areas [17].

This study aims to analyze the relationship between urban green spaces and air quality in different areas of the city. The analysis focused on four specific air pollutants to identify the areas most negatively affected by them and establish a relationship with the existing urban vegetation. Our study will also allow us to define air quality monitoring needs in different metropolitan (urban) areas to support the design of the necessary infrastructural development policies that are sustainable and consistent with the population's health.

2. Materials and Methods

2.1. General Description of the Study Area

This research was carried out in Santo Domingo, National District, capital of the Dominican Republic, center of the country's economic activities. Its geographical coordinates are 17°36′ and 19°58′ N and 68°19′ and 72°01′ W, located in the northern hemisphere, south of the Tropic of Cancer. (Figure 1). The city has a population of 965,040 inhabitants, and a floating population of 1 million people [10,18].

This geographic area has a surface area of 91.58 km^2, divided into three districts. The population of the National District is considered urban. Population growth in recent decades has focused on informal settlements, characterized by a deficit of public facilities and high population density. The average density for 2020 is 142.4 persons/km^2 [10].

2.2. Methods

A sampling grid was constructed to cover the entire 91.5 km^2 area of the National District. QGIS modeling software was used to define a grid of points with a distance of 2 km between each one, locating 27 sampling points, one of them in the National Botanical Garden (point 8) as a control point (Figure 2).

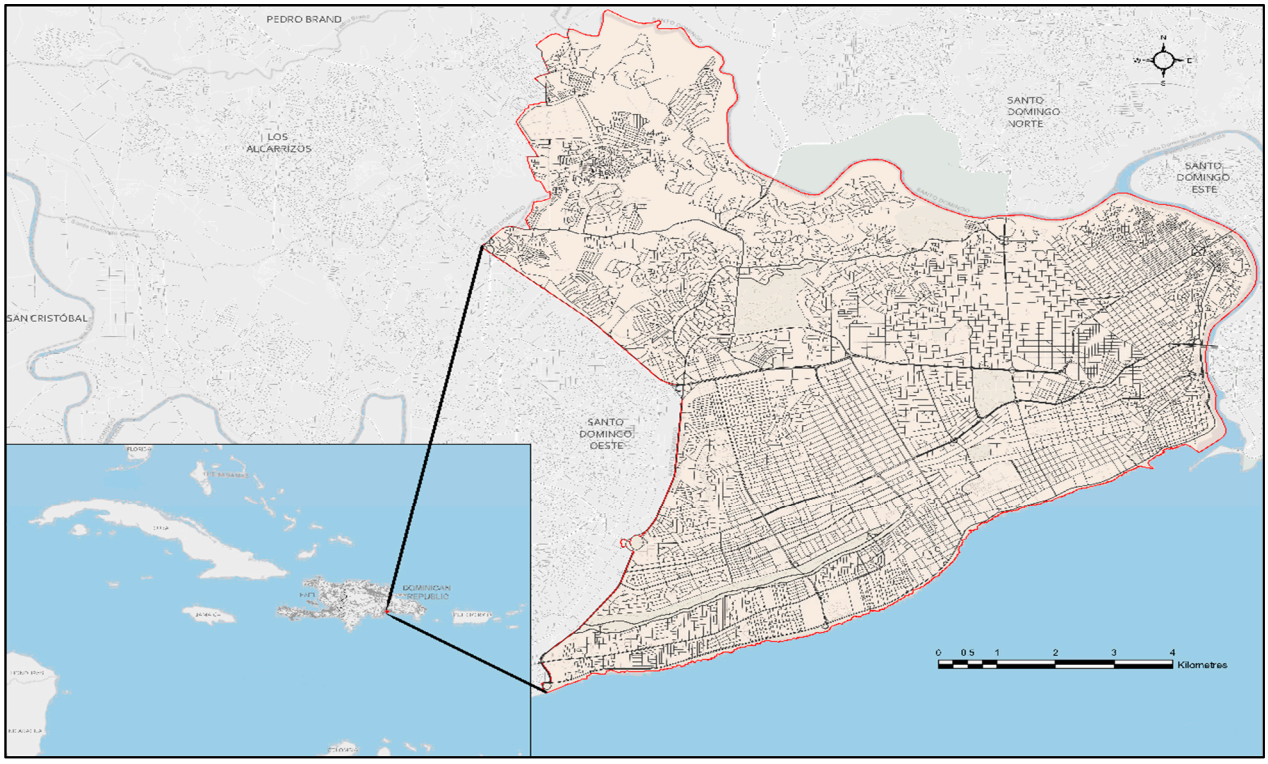

Figure 1. National District Location, Santo Domingo, Dominican Republic.

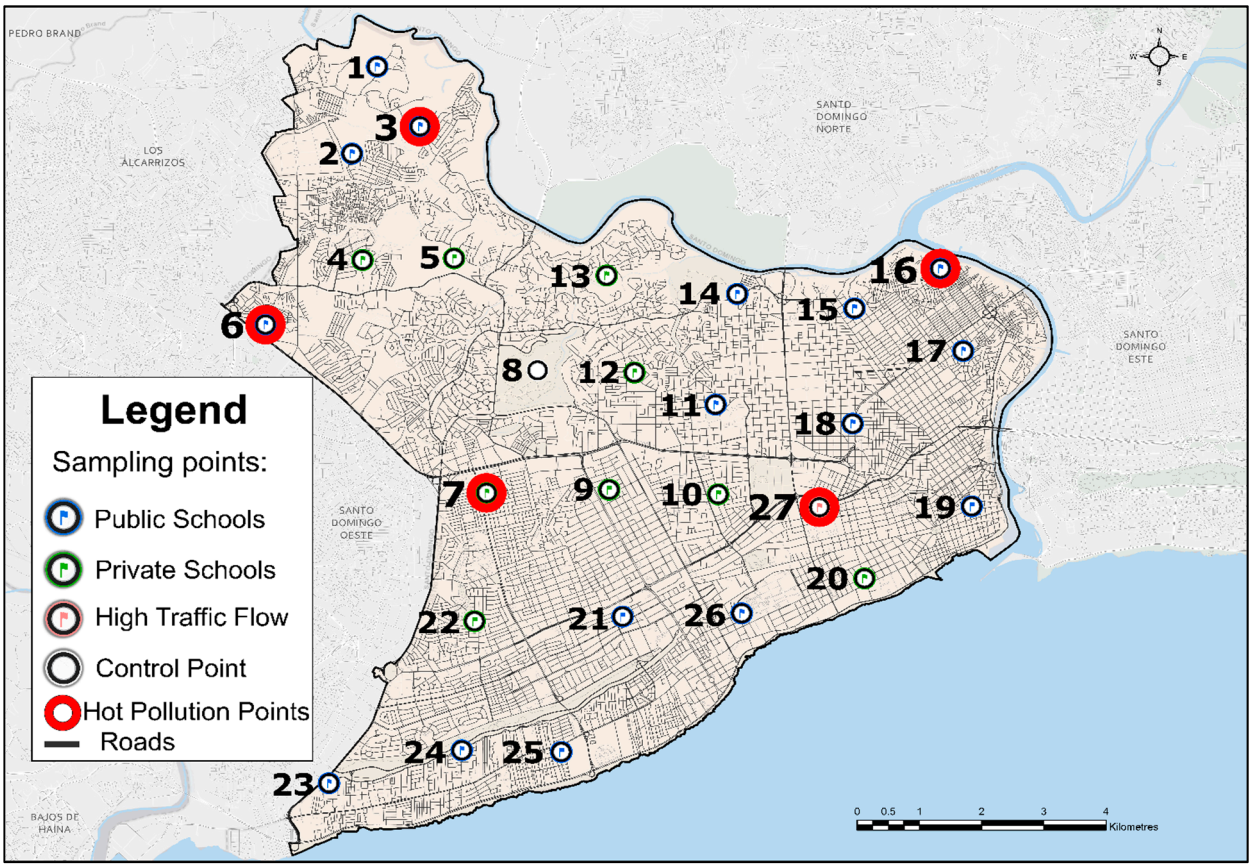

Figure 2. Sampling points and hot pollution points in Santo Domingo.

Active samplers (Air Metric Mini Vol TAS), with particulate matter collectors corresponding to a diameter of 10 μ, were used to measure the levels of suspended particles in the air (PM10). The method used to determine the concentration of particulate matter over a 24-h period was gravimetry. Filters were weighed before and after placement in the samplers on an analytical balance. Passive samplers were used to measure the immission levels of NO_2—SO_2 and CO pollutants. The measurement time for these types of pollutants was 30 days. Twenty-seven NO_2—SO_2 and 27 CO samplers were used each month.

The iTree Canopy tool was used to establish the levels of vegetation cover at the 27 sampling points. Table 1 shows the categories of the geospatial analysis of vegetation cover used.

Table 1. Description of selected categories for geospatial analysis of vegetation cover by iTree canopy. Source: Own elaboration.

Abbreviation	Type	Description
BS	Uncovered floor	Uncovered floor
GI	Green infrastructure	Lawns, shrubs and any other green surface except trees
GRI	Gray infrastructure	Buildings, cement, asphalt
O	Others	Any other Surface
T	Trees	Trees, not shrubs

i-Tree Canopy is a web-based software developed by the US Forest Service designed for the evaluation of the land and land use cover with photo interpretation of random points over satellite imagery obtained by google web service. The user considers each point selecting the categories previously configured in the project. This software estimates the ecosystems services of urban trees and provides their benefits related to reducing runoff and pollutants and carbon sequestration and storage.

In analyzing the immission levels at the sampling points, each pollutant was categorized according to measurements results and coverage percentage. A frequency analysis was performed on the results obtained. Data for each category was standardized to a range of 0.1 with INFOSTAT 2018 Software (National University of Córdoba, Córdoba, Argentina). A Pearson [19] principal component analysis (PCA) was performed to identify significant associations of the variables with each sample point. With this result, associated variables of importance were defined. Finally, Spearman's correlation analyses were performed between the four pollutants and the tree cover of each sample point (Appendix B).

3. Results

Immission levels show five points with the highest incidence of contamination levels compared to the remaining 22 points sampled (Figure 2). These points are 3, 6, 7, 16 and 27.

The average vegetation cover, as a result of the measurements in the iTree Canopy sampling sites, is 26.05%, highlighting the Botanical Garden (point 8) as the upper limit, with 76.7% and the point 19 as the lower limit with 0.3% vegetation cover (Figure 3, Appendix A).

The principal component analysis shows that according to WHO [20], the maximum annual allowed levels for particles and air pollutants measured in this investigation are: for NO_2 40 μg/m^3, for SO_2 20 μg/m^3 and for PM10 20 μg/m^3. However, this agency does not have a monthly measurement parameter, so it is impossible compare directly. However, taking WHO values as an indicator for estimating the level of contamination in Santo Domingo, we found that points 7 and 27 exceed the levels of Nitrogen Dioxide (NO_2) and neither sampling point exceeds the maximum permissible levels of Sulfur Dioxide (SO_2) nor Carbon Monoxide (CO). However, point 27 shows a high value in SO_2 compared to the other sampling points that might be explained by the high flux traffic in this point of the city.

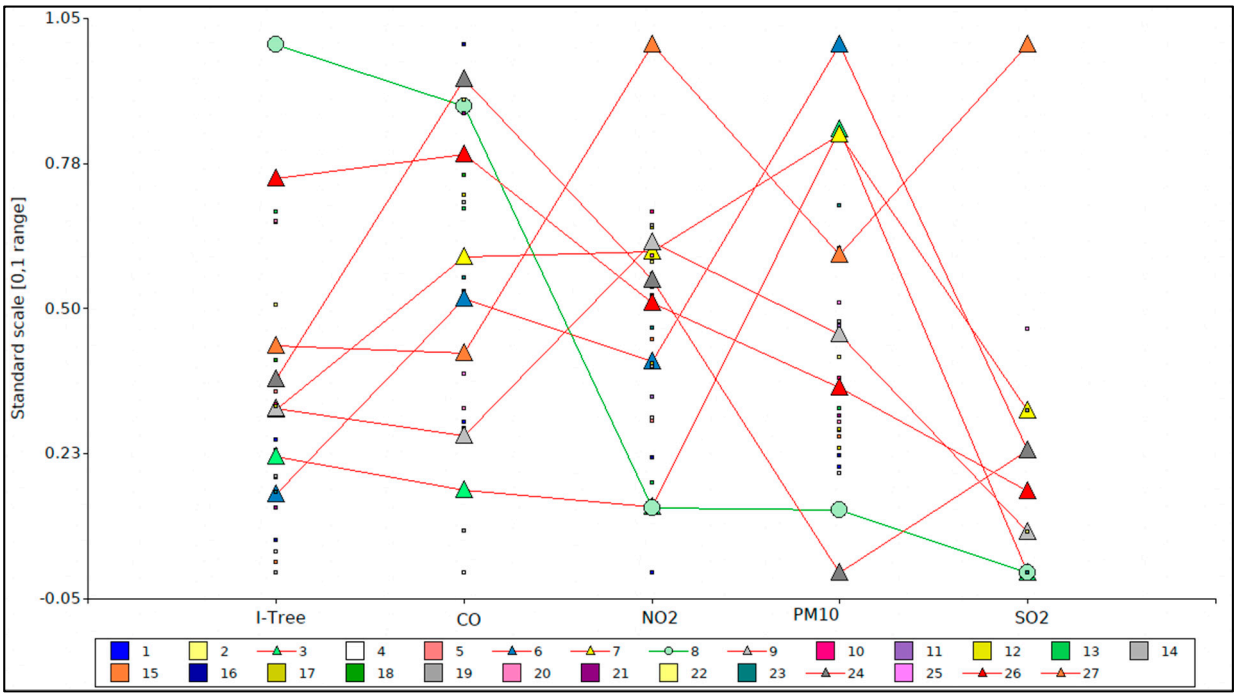

Figure 3. Results of pollutant (NO_2, PM10, SO_2 and CO_2) and green infrastructure measurements (Itree-canopy) at the 27 sampling points in the National District. For sampling points location, see Figure 1.

In the case of 10-micron Particulate Matter (PM10), this pollutant is present in 6 of the 27 sampled points with levels that exceed WHO parameters [20]. These points are: 3, 6, 7, 16, 23 and 27, representing 22% of the measurement points. The principal component analysis shows a significant association between some sampling points with CO and PM10; however, for pollutants such as NO_2 and SO_2 only point 27 is significantly associated (Table 2, Figure 4 and Appendices B and C).

Table 2. Significant correlations between the variables studied and the sampling points (Note: *, or ** indicate significant nonlinear dependencies at the 5%, or 1% levels, respectively).

Variable (1)	Variable (2)	*n*	Spearman	*p*-Value
Sampling points	SO_2	27	0.5460	0.0032 **
Sampling points	NO_2	27	0.3956	0.0437 *
Sampling points	CO	27	0.5408	0.0036 **
Sampling points	Forest cover	27	0.3938	0.0447 *

The principal component analysis relating to tree cover and air quality did not establish a positive correlation between both variables in the sample points (Table 2, Figure 5 and Appendices C and D).

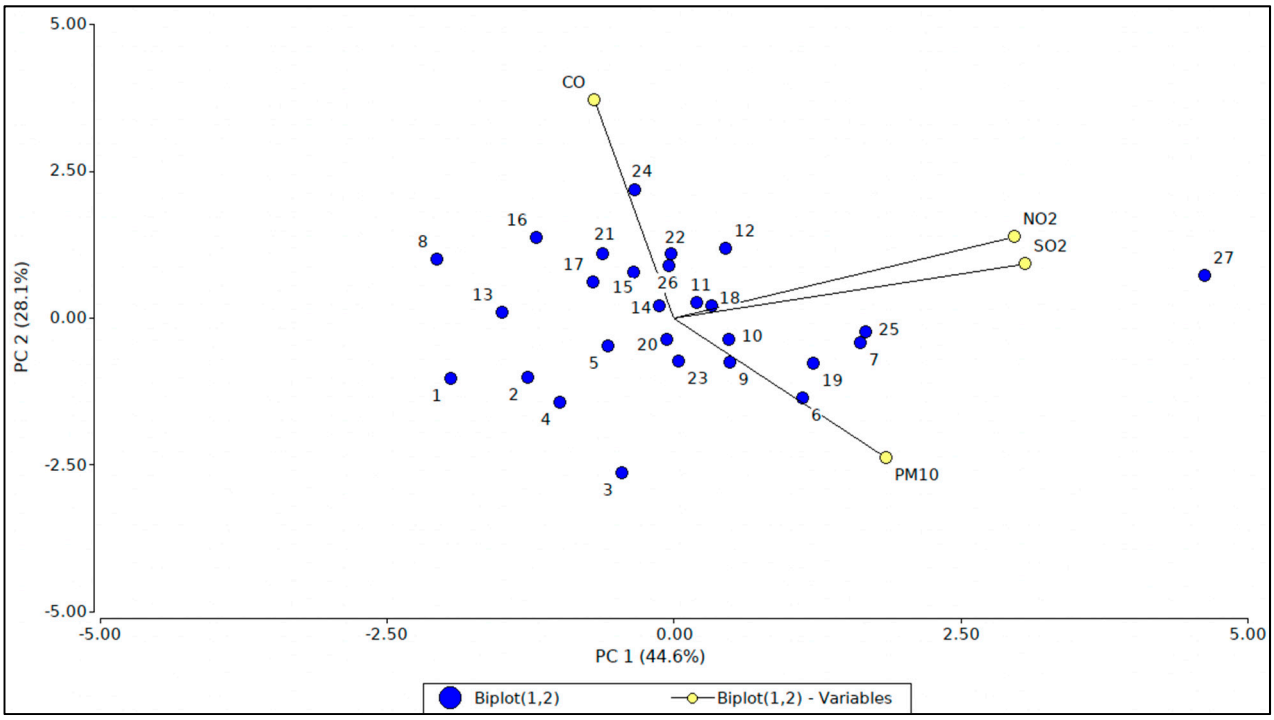

Figure 4. Principal component analysis for the four pollutants studied. For sampling points location, see Figure 1.

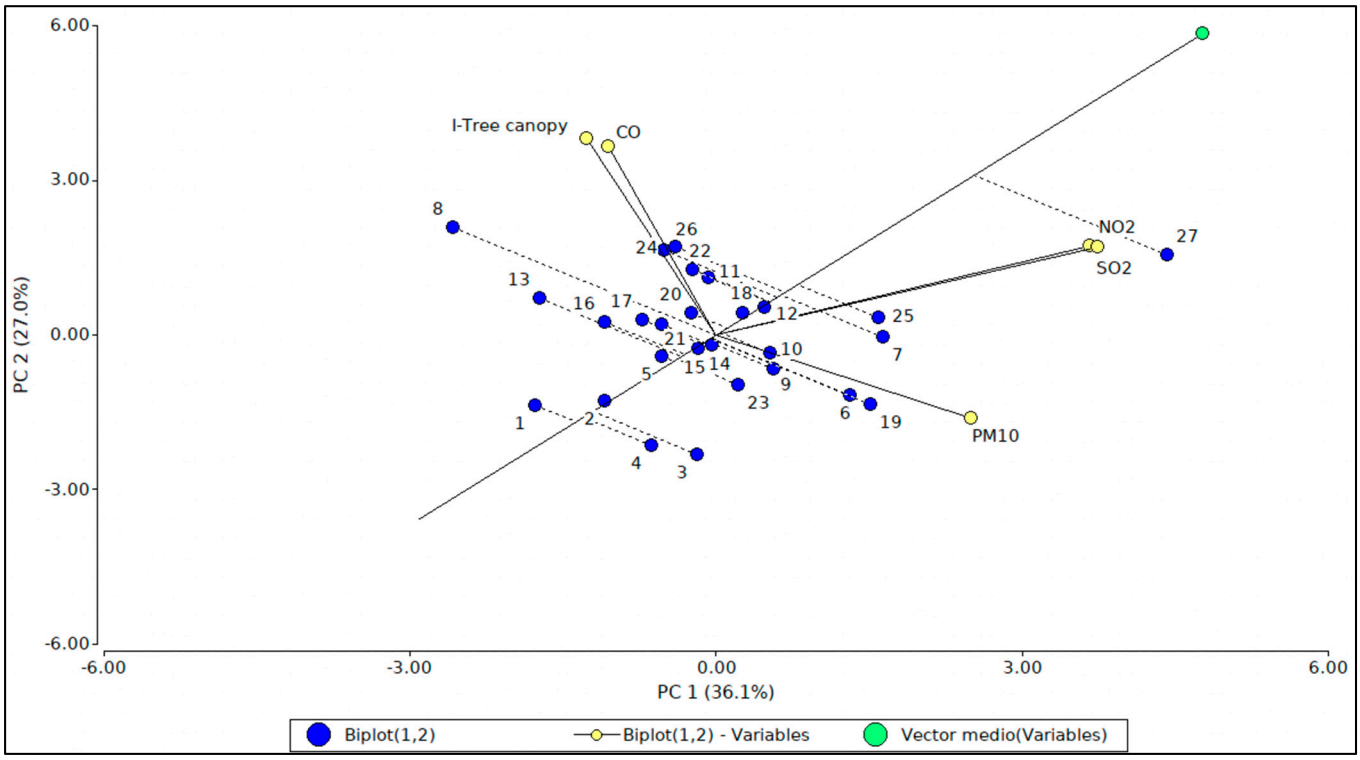

Figure 5. Principal component analysis correlation between pollutants and vegetation cover. For sample points location see Figure 1.

4. Discussion

Studies that have conducted specific monitoring for criteria pollutants concentrations such as PM10, carbon monoxide and other combustion gases such as NO_2, have found significant correlations between vegetation cover and air quality [21]. In contrast to the

results obtained in this research, there is a positive statistical correlation between SO_2 and NO_2 pollutants, which suggests points in the city exposed to the same types of emitters. Still, no correlation was identified between forest cover and the measured pollutants. It should be noted that although there is no statistical correlation between most of the pollutant variables, it is observed that the higher the forest cover (Figure 3), the lower the presence of pollutants and the higher the forest cover (Figure 3), the lower the presence of pollutants and the higher the presence of CO. The latter has a negative correlation with NO_2 (Appendix B), so it is assumed that forest cover has a direct influence on the removal of pollutants. Pollution removal and human health effects are substantially greater in rural than urban areas, where vegetation cover is more abundant than gray infrastructure [22–25]. Vegetation types and species also play an essential role [3,26].

The increase in the Dominican Republic's vehicle fleet is an important factor to consider; its average annual percentage growth is 6.85%, so that by 2025, the vehicle fleet is expected to exceed 6 million units [27]. Some studies state that transport emissions are an essential factor of air pollution in cities worldwide, causing respiratory and cardiovascular diseases [25,26].

A study conducted by UN Environment Programme [27] in the city of Santo Domingo, to establish the impact of the vehicle fleet on particulate matter, found a statistically significant positive correlation between vehicular traffic and $PM_{2.5}$ particulate matter. Likewise, PM10 measurements at the only monitoring station in the National District, presents results above the WHO parameters [20], as of 2015 [28].

These results are consistent with the metadata study by Karagulian et al. [29], which analyzes studies in more than 500 cities worldwide, measuring different pollutants, with traffic contributing 25% of PM10 concentrations. Analyses of air quality trends in the Latin American and Caribbean region indicate that there have been substantial increases in Greenhouse Gas (GHG) concentrations, exceeding the planet's limits for climate change, with traffic being one of the major contributors [27]. An association between NO_2 and SO_2 is observed, suggesting points exposed to the same types of pollutants in the city.

The city of Santo Domingo does not have a permanent air quality monitoring network, nor previous published and validated studies, that allow the results of this study to be analyzed and compared. The effectiveness of the measurement of passive samplers and the ratio of green and gray infrastructure at the sampling points are factors to be considered for the results of this research. Studies have been conducted relating the impact of some green infrastructure designs on air quality [1,3,22,26,30]. Environmental quality of the city implies working comprehensively in urban planning, considering elements such as pollution sources [9,31], efficient regulations, green infrastructure that contemplates effective species for the city [32], its proper planning and augmentation [24,33].

5. Conclusions

Particular attention should be paid to five hot spots in the National District due to the presence of criteria pollutants, those spots were 3, 6, 7, 16 and 27. Although there is no statistical correlation between tree cover and the pollutants measured, it is observed that the higher the forest cover, the higher the CO and the lower the presence of particles and contaminants. A permanent monitoring system is needed in order to establish strong relationships between these elements and be able to obtain adequate indicators comparable to WHO standards that contribute to decision-making in urban planning and the design of appropriate public policies.

It is necessary to also consider actions against other elements such as transportation, electricity generators, industry, and the design and management of urban green infrastructure, which are known to have a high contribution to air pollution.

Urban planning and territorial management of cities should develop green spaces that consider viable and appropriate species for cities according to their ecosystem characteristics and biodiversity of flora and fauna. It is crucial to conserve the city's peripheral green areas and expand green infrastructure in the centers of urban areas.

Our study is the first to provide data for the city of Santo Domingo, highlighting the importance of managing the ecosystem services of the urban forest, such as air quality, and the importance for sustainable development of having this type of information for decision makers.

Author Contributions: Conceptualization, Methodology, Writing—original draft, Data curation, Validation, Supervision, Writing—review & editing. S.B.-D. Review & editing C.C.G., U.J.J.-H., L.C.R., A.G.-G., Validation, U.J.J.-H. Visualization, Writing—review & editing. S.B.-D., U.J.J.-H., C.C.G. All authors have read and agreed to the published version of the manuscript.

Funding: PEER-NAS 5-400 Grant, Program and Fondo de Agua Yaque del Norte, Dominican Republic, and the Regional Government of Extremadura (Junta de Extremadura) through grant GR18075.

Data Availability Statement: The database will be available at https://infoclima.intec.edu.do/ in December 2021.

Acknowledgments: The authors acknowledge the financial support from Project 5–400 of the PEER-NAS Cycle 5 program and Fondo de Agua Yaque del Norte, Dominican Republic, and the Regional Government of Extremadura (Junta de Extremadura) through grant GR18075. The authors acknowledge the helpful comments received from Carol Franco Billini (Virginia Tech University), Alma Liz Vargas de la Mora and Victor Gomez-Valenzuela (INTEC) on previous versions of this paper. The authors also acknowledge the helpful support received from Ana Pou and Jose Miguel Martinez regarding the field data collection.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Percentage of Green Infrastructure in the 27 Sampling Points

Sample Points	% Green Infrastructure
1	19.5
2	18
3	17
4	3.3
5	26.4
6	11.6
7	23.9
8	76.7
9	24
10	24.6
11	51
12	14
13	52.5
14	14.2
15	1.72
16	5
17	24.3
18	31
19	0.3
20	51.2

Sample Points	% Green Infrastructure
21	9.6
22	39
23	12
24	28.3
25	33.7
26	57.3
27	33.2

Source: Own elaboration with field data.

Appendix B. Spearman's Correlation of the Studied Variables

Variable (1)	Variable (2)	*n*	Spearman	*p*-Value
NO_2	NO_2	27	1	<0.0001
NO_2	PM10	27	0.28	0.15
NO_2	SO_2	27	0.55	0
NO_2	CO	27	−0.02	0.93
NO_2	Forest cover	27	0.02	0.91
NO_2	Sampling point	27	0.4	0.04
PM10	NO_2	27	0.28	0.15
PM10	PM10	27	1	<0.0001
PM10	SO_2	27	0.24	0.23
PM10	CO	27	−0.24	0.23
PM10	Forest cover	27	0.06	0.77
PM10	Sampling point	27	−0.07	0.73
SO_2	NO_2	27	0.55	0
SO_2	PM10	27	0.24	0.23
SO_2	SO_2	27	1	<0.0001
SO_2	CO	27	0.08	0.68
SO_2	Forest cover	27	0.01	0.96
SO_2	Sampling point	27	0.22	0.26
CO	NO_2	27	−0.02	0.93
CO	PM10	27	−0.24	0.23
CO	SO_2	27	0.08	0.68
CO	CO	27	1	<0.0001
CO	Forest cover	27	0.24	0.23
CO	Sampling point	27	0.54	0
Forest cover	NO_2	27	0.02	0.91
Forest cover	PM10	27	0.06	0.77
Forest cover	SO_2	27	0.01	0.96
Forest cover	CO	27	0.24	0.23
Forest cover	Forest cover	27	1	<0.0001
Forest cover	Sampling point	27	0.39	0.04
Sampling point	NO_2	27	0.4	0.04
Sampling point	PM10	27	−0.07	0.73
Sampling point	SO_2	27	0.22	0.26
Sampling point	CO	27	0.54	0
Sampling point	Forest cover	27	0.39	0.04
Sampling point	Sampling point	52	1	<0.0001

Appendix C. Principal Component Analysis of Figure 4

Eigenvalues

Lambda	Value	Proportion	Prop Acum
1	1.78	0.45	0.45
2	1.12	0.28	0.73
3	0.74	0.19	0.91
4	0.35	0.09	1.00

Eigenvectors

Variables	e1	e2
NO2	0.63	0.29
PM10	0.39	−0.51
SO2	0.65	0.20
CO	−0.15	0.79

Appendix D. Principal Component Analysis of Figure 5

Eigenvalues

Lambda	Value	Proportion	Prop Acum
1	1.80	0.36	0.36
2	1.35	0.27	0.63
3	0.81	0.16	0.79
4	0.69	0.14	0.93
5	0.34	0.07	1.00

Eigenvectors

Variables	e1	e2
Itree-canopy (%)	−0.17	0.61
NO2	0.61	0.29
PM10	0.41	−0.27
SO2	0.62	0.28
CO	−0.21	0.63

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