sustainability

MDPI

Article

Building Urban Resilience with Nature-Based Solutions: A Multi-Scale Case Study of the Atmospheric Cleansing Potential of Green Infrastructure in Southern Ontario, Canada

Vidya Anderson [1,*], Matej Zgela [2] and William A. Gough [1]

[1] Climate Lab, Department of Physical and Environmental Sciences, University of Toronto Scarborough, Toronto, ON M1C 1A4, Canada; william.gough@utoronto.ca
[2] Department of Geophysics, Faculty of Science, University of Zagreb, Horvatovac 95, 10000 Zagreb, Croatia; matej.zgela@gfz.hr
* Correspondence: vidya.anderson@utoronto.ca

Abstract: Green infrastructure is a nature-based solution that supports sustainable development and restores urban, suburban, and peri-urban environments. Using a multi-scale evaluation, this study explores the impact of the application of green infrastructure, as a form of atmospheric cleansing, on tropospheric nitrogen dioxide. The impacts are not limited to specific green infrastructure treatments nor geographic location and land use type. Using both site-specific stationary air monitoring and coarser resolution satellite derived remote sensing, this study demonstrates the nature-based remediation effect of green infrastructure on nitrogen dioxide concentrations in Southern Ontario, Canada. At these scales, remote sensing and stationary air monitoring observations support the hypothesis that green infrastructure can cleanse the atmosphere by reducing nitrogen dioxide through scavenging by trees and dense vegetation at the neighbourhood level, consistent with the findings from microscale field campaigns. The study showed a clear link between compact, built-up, industrialized areas and higher nitrogen dioxide levels at the mesoscale, particularly notable to the west of the city of Toronto. Nature-based solutions provide an opportunity to address the impacts of urbanization, increase climate resilience, and support healthy urban environments.

Keywords: green roofs; green walls; urban vegetation; urban forestry; tree-based intercropping; air pollution; built environment; urban design

check for updates

Citation: Anderson, V.; Zgela, M.; Gough, W.A. Building Urban Resilience with Nature-Based Solutions: A Multi-Scale Case Study of the Atmospheric Cleansing Potential of Green Infrastructure in Southern Ontario, Canada. *Sustainability* **2023**, *15*, 14146. https://doi.org/10.3390/su151914146

Academic Editors: Kim Neil Irvine, Lloyd Hock Chye Chua and Niall Kirkwood

Received: 15 August 2023
Revised: 29 August 2023
Accepted: 12 September 2023
Published: 25 September 2023

1. Introduction

Deployment of nature-based solutions (NbS) is gaining recognition globally as an essential planning and design practice to increase urban resilience and promote sustainable development. The International Union for Conservation of Nature has defined NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [1–3]. The NbS concept has been articulated at the intersection of science and policy, encompassing research from across different disciplines, such as atmospheric physics, chemistry, environmental science, environmental studies, ecology, sociology, political science, engineering and architecture to name a few, and thus providing an interdisciplinary linkage between specialists and generalists. While there is agreement that NbS can address challenges such as climate change, understanding their characteristics, how they work as a complex intervention, and the multiple co-benefits that can be leveraged through strategic application, is essential to demonstrating how NbS can truly enhance resilience and sustainability. In this study, the potential for atmospheric cleansing of nitrogen dioxide is explored as one of these co-benefits.

Air pollution is a key challenge for urban sustainability. In urban areas, air quality is influenced by local pollution sources such as industrial and transportation emissions [4].

These air pollutant sources contribute to the accumulation of greenhouse gases and particulate matter that have longer term impacts on climate. Solar and terrestrial radiation interact with air pollutants affecting the energy balance of the Earth and changing the climate [5,6]. Climate change influences air pollution through changes in the intensity, duration and frequency of various meteorological phenomena including atmospheric blocking, heat waves, and precipitation extremes [6–11]. In urbanized areas, activities including agricultural production, building functions, energy generation, fossil fuel combustion, industrial processes, land use and natural resource development, and transportation, all generate greenhouse gas (GHG) emissions [12]. Agricultural activity accounts for approximately 25 percent of total global GHG emissions and 8 percent of total provincial GHG emissions in Ontario, Canada [13,14]. The built environment accounts for approximately 20 percent of total global and 24 percent of Ontario's total GHG emissions [12,14]. Industry accounts for approximately 30 percent of total global and 28 percent of Ontario's total GHG emissions [14,15]. Transportation accounts for approximately 23 percent of total global and 35 percent of Ontario's total GHG emissions [14,16].

Nitrogen dioxide (NO_2), the specific focus of this study, is an abundant gaseous pollutant generated predominantly in urbanized settings [17]. High concentrations of nitrogen dioxide occur in areas with dense built form requiring heating and cooling capacity, heavy industrial land use, and high volumes of vehicular traffic [18]. Thus, nitrogen dioxide has become a marker of progress and economic development. It is also an identified air pollutant of public health concern across urbanized areas [19–22]. Exposure to elevated levels of nitrogen dioxide can lead to adverse health outcomes that include respiratory illnesses and disease such as asthma and lung cancer, in addition to increased mortality and morbidity [23–28].

In this study, the remediative effect of nature-based solutions (NbS) on tropospheric nitrogen dioxide is explored. As noted above, the International Union for Conservation of Nature has defined NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [1–3]. This umbrella definition includes five classifications of ecosystem-based approaches, one of which is green infrastructure [1–3]. The nature-based remediation effect of green infrastructure can reduce concentrations of air pollutants such as nitrogen dioxide and increase climate resilience across urban, suburban, and peri-urban environments. The focus of this study is the atmospheric cleansing potential of green infrastructure on nitrogen dioxide concentrations in Southern Ontario, Canada. In the following section, green infrastructure as an NbS is reviewed.

Literature Review

Green infrastructure provides multiple benefits, including the regulation of temperature and mitigation of the intensity of the urban heat island, in addition to abatement of gaseous pollutants such as ozone and nitrogen dioxide [29–41]. Research has shown that green infrastructure can reduce urban GHG emissions, improve building energy efficiency, and sequester carbon dioxide [29,30,34,38,40,42–47]. In addition to reducing the carbon footprint arising from conventional food production and distribution, green infrastructure such as urban agriculture systems provide multiple ecosystem services [38–41,48,49]. Urban agriculture systems can improve food security while reducing pressures on conventional agriculture when industrial-scale production is impacted by meteorological extremes [40,49–51]. Tree-based intercropping systems are another example of green infrastructure that can reduce agricultural GHG emissions through increased canopy cover and decreased reliance on fertilizers and pesticides [52,53]. These systems can provide carbon sinks in the woody biomass of the trees and through enhanced soil carbon capacity [53].

Applications of green infrastructure, such as green roofs and walls, have demonstrated an improvement in air quality and regulation of temperature, in addition to improving human health outcomes associated with air pollution and extreme heat [35,38–41,54–64].

Deposition and immobilization of localized air pollutants such as ozone, nitrogen dioxide, and particulate matter occurs through the application of green roofs, green walls, and urban vegetation and forestry, which can ameliorate local air quality [32,33,35–37,44,54,60,63–67].

Common functions, shared across applications of green infrastructure, are illustrated in Figure 1, as well as others that are exclusive to specific forms. Within this study, green infrastructure applications have been grouped into five categories that include green roofs, green walls, urban vegetation and forestry, urban agriculture systems, and tree-based intercropping systems. Each application is a nuanced nature-based intervention with unique characteristics and a range of co-benefits including air pollutant amelioration, biodiversity and pollinator support, building energy efficiency, carbon sequestration, temperature regulation, and stormwater management.

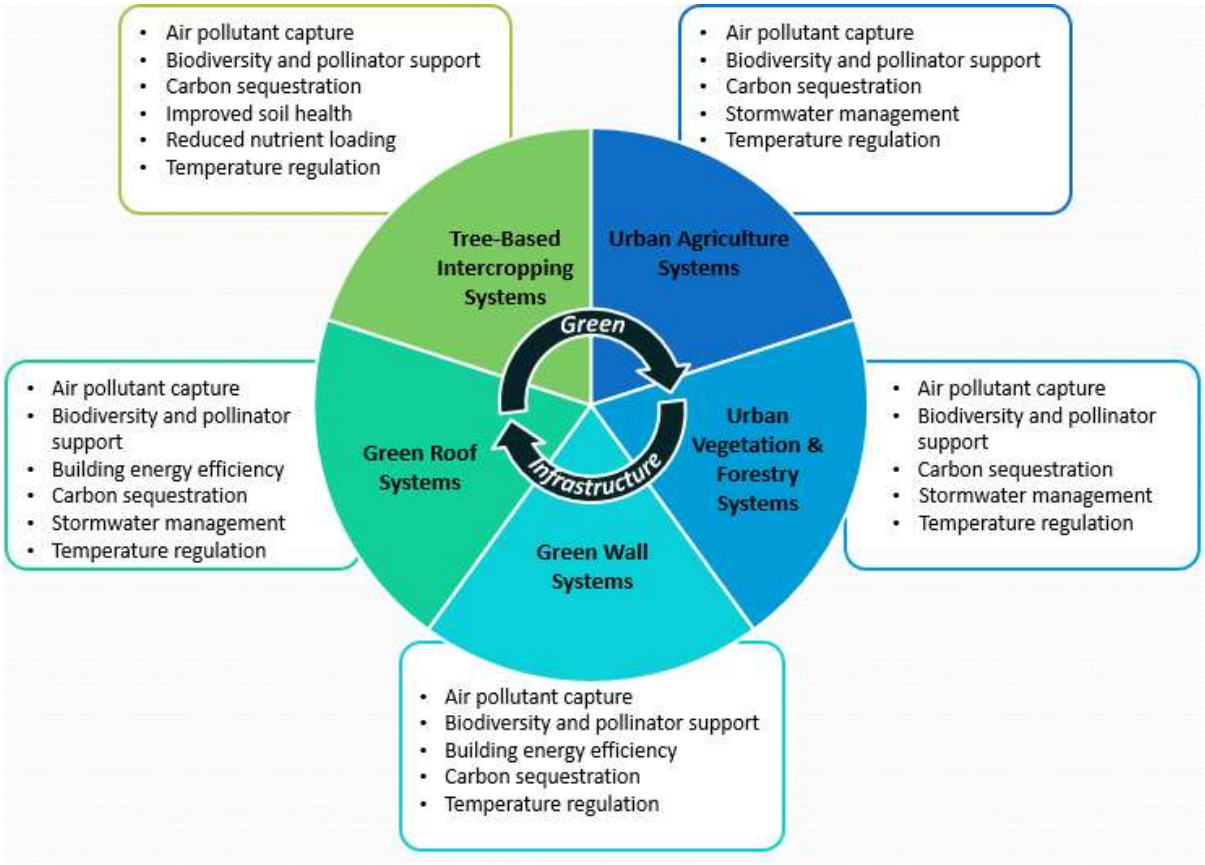

Figure 1. Green infrastructure form and function [38–41,49–51,68,69].

Green roofs are characterized as extensive or intensive, depending on substrate depth. Extensive roofs weigh less and have a shallower depth, which facilitates building retrofits and enables sloped roof installation. Intensive green roofs have a deeper soil layer, which allows for more variety in the type of vegetation used [30]. Green walls are vertical surfaces overlaid by vegetation or configured with planted structures affixed to the building surface and automatically irrigated [43,70]. Urban vegetation and forestry systems can include bioswales, shrubs, rain gardens, trees, and woodlots [35,54,70]. Urban agriculture systems include growing roofs, rooftop gardens, and community gardens [48,71,72]. Tree-based intercropping systems are croplands interspersed with trees and shrubs [52].

Green infrastructure research to date has primarily focused on specific applications and discrete benefits [32–37,42,43,45,46,53,54,57,60,62,63,67,73–81]. Studies of the air quality benefits of green infrastructure have examined individual applications of green infrastructure [35–37,54,66,67]. Anderson and Gough (2020) [38], in a field campaign in Southern Ontario, Canada, measured the potential of multiple applications of green infrastructure to

reduce air pollutant concentrations at the microscale and site level, including green roofs, green walls, urban vegetation and forestry, urban agriculture systems, and tree-based intercropping systems (Figure 1). This field-based study undertook data collection using a range of green infrastructure applications and different morphologies to evaluate how different green infrastructure applications ameliorate air pollution, across location, geography, and land-use type. A reduction in nitrogen dioxide in nearly every instance was observed with an average reduction of 0.11 parts per million (ppm) across all sites and applications of green infrastructure, as reproduced in Figure 2 [38].

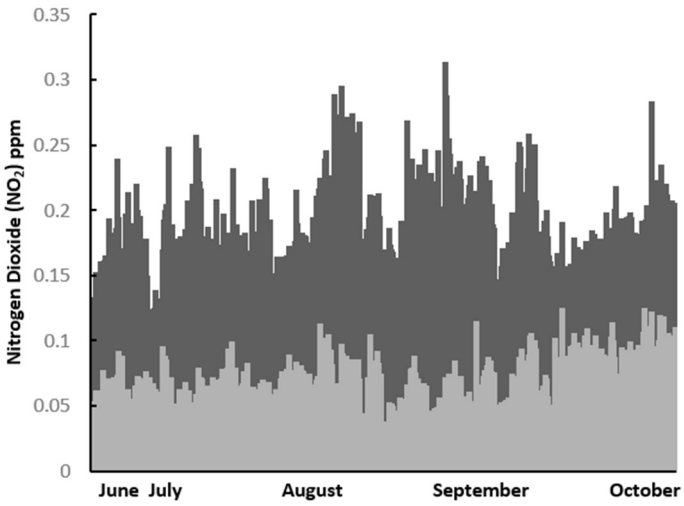

Figure 2. Difference (ppm) between test and control sites for nitrogen dioxide (NO_2) from June to October 2017 in Southern Ontario, Canada. ■ Control ■ Test [38].

This observed reduction of 0.11 ppm in nitrogen dioxide across all green infrastructure sites and applications, representing an average reduction of 65 percent [38]. A total of nine individual field study sites (Figure 3) were evaluated across different urban, suburban and peri-urban environments within the five green infrastructure categories as shown in Figure 1 from [38]. Consistent field-based results were reported in [35–37]. These studies provide the microscale foundation for the current work which demonstrates atmospheric cleansing by exploring the same nitrogen dioxide reduction potential at local and regional scales. For the mesoscale, the relevant form of green infrastructure shifts and is largely focused on urban vegetation and forestry.

Thus, building on this collective work we have undertaken to evaluate the air quality benefits of green infrastructure at the site level and microscale, this comparative analysis seeks to evaluate the nature-based remediation effect at the neighbourhood level and meso-scale by answering the following questions:

(1) Is there a measurable nature-based remediation effect in tropospheric nitrogen dioxide concentrations using a range of green infrastructure applications (Figure 1) across different morphologies in Ontario, Canada, regardless of location, geography, or land use type?
(2) Are the nature-based remediation effects of green infrastructure on nitrogen dioxide concentrations visible by satellite imagery?
(3) Do parts of Ontario, Canada have higher concentrations of nitrogen dioxide due to the density of built-up surfaces or proximity to point sources?

This study evaluates how nature-based solutions can play a role in reducing nitrogen dioxide concentrations at a city scale. Remote sensing and stationary air monitoring measurements were used to evaluate the impacts of green infrastructure on nitrogen dioxide concentrations in Southern Ontario, Canada.

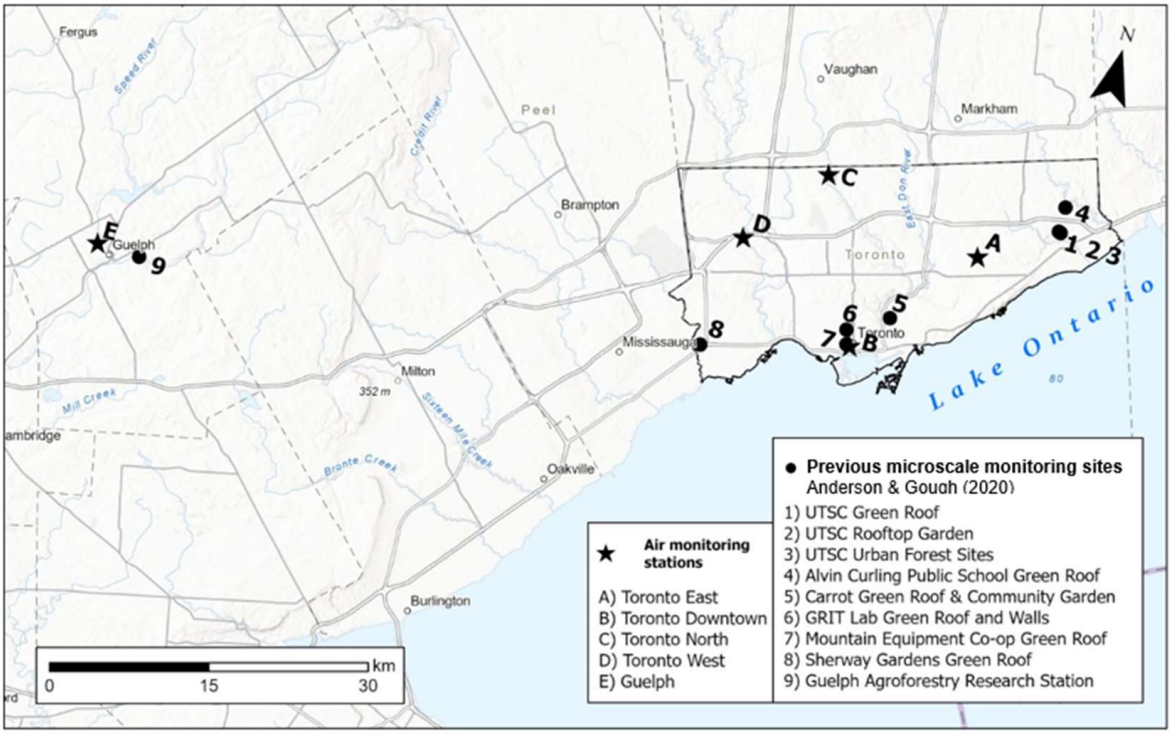

Figure 3. Map of air monitoring stations and previous microscale monitoring sites [38].

2. Methods

The previously published microscale results showed that green infrastructure can provide a sink for air pollutants at the site level [35–38,54,67]. Together, these studies provide a lens to evaluate how different green infrastructure applications can ameliorate air pollution at coarser scales. Two data sets were examined to assess the potential impact of green infrastructure at coarser scales.

The first analysis used remote sensing from July to October 2018. The analysis of this spatial data set sought to understand the spatial differences in nitrogen dioxide based on surface source/sink considerations informed by the microscale results of Anderson and Gough (2020) [38] and others [35–37]. This was accomplished using the spatial distribution of nitrogen dioxide column densities observed by the Sentinel-5P satellite at approximately a one-kilometre resolution, and the normalized difference vegetation index (NDVI) observed by the Landsat-8 satellite. This allowed for a correlation of nitrogen dioxide distribution and NDVI to urbanized areas and changes over different land use types. Nitrogen dioxide column densities are visible by satellite and are not precisely identical to nitrogen dioxide concentrations measured in-situ as undertaken during a microscale field campaign [38].

The second analysis was carried out to address the potential complication of using column integrated satellite derived nitrogen dioxide; hourly nitrogen dioxide data from five provincial air monitoring stations was retrieved and analyzed for the June to October period for 2017 and 2018 to augment and contextualize the satellite data. This data is measured and recorded hourly, and made publicly available by the Ontario Ministry of the Environment, Conservation, and Parks (i.e., http://www.airqualityontario.ca, accessed on 10 July 2022). Data was accessed for the summer periods of 2017 and 2018 period, coincident with [38] and the satellite data described above, for four locations in Toronto, Ontario and one in Guelph, Ontario.

2.1. Study Areas

The Anderson and Gough (2020) field study evaluated a total of nine individual field study sites across different urban, suburban and peri-urban morphologies [38]. To

build on those results and investigate the air quality benefits of green infrastructure at the neighbour level and meso-scale, five provincial air monitoring stations (Figure 3) in proximity to the individual field microscale study sites [38,82], were selected to analyze neighbourhood-level nitrogen dioxide data, in addition to the nitrogen dioxide column densities shown through the larger scale satellite imagery. The four Toronto locations are designated Toronto West (43.71° N, 79.54° W), Toronto East (43.75° N, 79.27° W), Toronto North (43.78° N, 79.47° W) and Toronto Downtown (43.66° N, 79.39° W), as shown in Figure 3. The air intake at Toronto West is 8 m, 4 m at Toronto North and Toronto East and 10 m at Toronto Downtown. The Guelph location (43.55° N, 80.26° W) is a peri-urban setting, and the intake is at 4 m.

The Guelph air monitoring station is located at the edge of the Exhibition park in a residential area of this small city (Figure 3). The Toronto West station is located near the intersection of major provincial highways in an industrial section of this large metropolitan city, and is adjacent to a large industrial region to the west of the station. The Toronto Downtown station is located at the busy intersection of Bay and Wellesley streets in the downtown core, located east of the University of Toronto St. George campus. The Toronto East station is located at a busy residential intersection in an eastern suburb of Toronto, Ontario, Canada. The Toronto North station is centrally located near the northern boundary of the city. Significant industrial areas exist to the west and northwest of the air monitoring stations, with substantial green space to the east.

2.2. Data Collection

During the satellite data collection campaign, high-resolution data of nitrogen dioxide concentrations captured by TROPOMI (TROPOspheric Monitoring Instrument), located aboard the Sentinel-5P satellite developed by the European Space Agency, were retrieved and analyzed. The data set "Sentinel-5P OFFL NO2: Offline Nitrogen Dioxide" was accessed via Google Earth Engine (GEE), a cloud-based geospatial analysis platform [83]. Data set availability begins on June 28 of 2018 and continues onwards with a spatial resolution of 1113.2 m. TROPOMI measures the total vertical column of nitrogen dioxide but can differentiate between tropospheric and stratospheric columns as well. Since most air pollution resides in the troposphere, the mean tropospheric vertical column of nitrogen dioxide was calculated for the period from 1 July to 31 October 2018.

Additionally, GEE was also used to calculate the mean NDVI for the period of June 1 to October 31 of 2018 from the Landsat-8 satellite. NDVI was calculated as a normalized difference of Bands 4 and 5 of the Operational Land Imager (OLI) sensor aboard Landsat-8 [84]. NDVI was originally accessed in 30 m spatial resolution but was later resampled in GIS to the native resolution of the nitrogen dioxide data set (1113.2 m) using the nearest neighbour interpolation method. NDVI and nitrogen dioxide correlation analysis was then performed. GIS and statistical analysis of nitrogen dioxide and NDVI data was completed using ArcGIS Pro 2.9.0. software. The satellite data were augmented by the observations of nitrogen dioxide collected at the five provincial air monitoring stations (Figure 2) for the period from June to October in 2017 and 2018.

3. Results

The data collected through remote sensing and station observations were used to evaluate the impact of green infrastructure on nitrogen dioxide concentrations.

3.1. Meso-Scale Nitrogen Dioxide Abatement

As shown in Figure 4, NDVI is a measure of relative biological productivity. Areas in green are high in productivity, reflective of treed and vegetated landscapes, while areas of orange have low productivity.

In comparison to Figure 5, areas with peak levels of nitrogen dioxide coincide with the industrialized neighbourhoods immediately to the west of Toronto (i.e., northern Peel region). Figure 5 represents the net balance of sources and sinks of nitrogen dioxide. This

includes areas of nitrogen dioxide production (i.e., industry as well as vehicular traffic) and uptake (i.e., green infrastructure reductions of nitrogen dioxide concentrations as demonstrated in [38]).

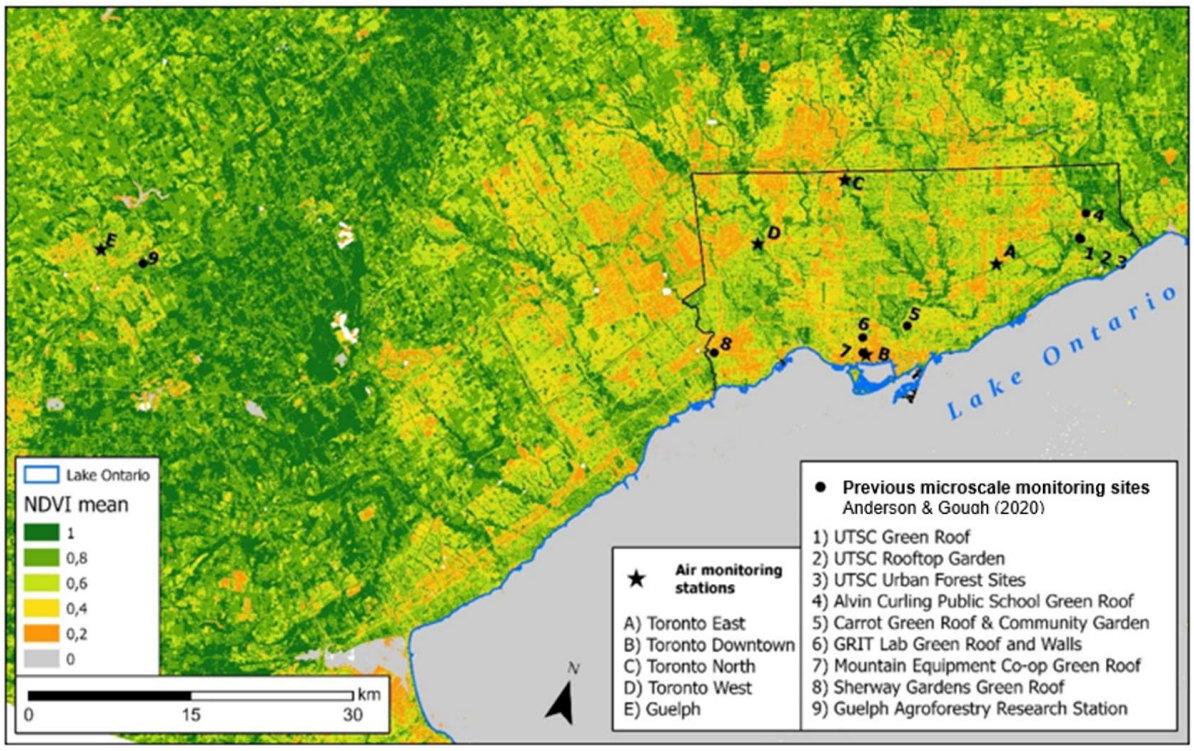

Figure 4. Spatial distribution of mean NDVI from June to October 2018 [38].

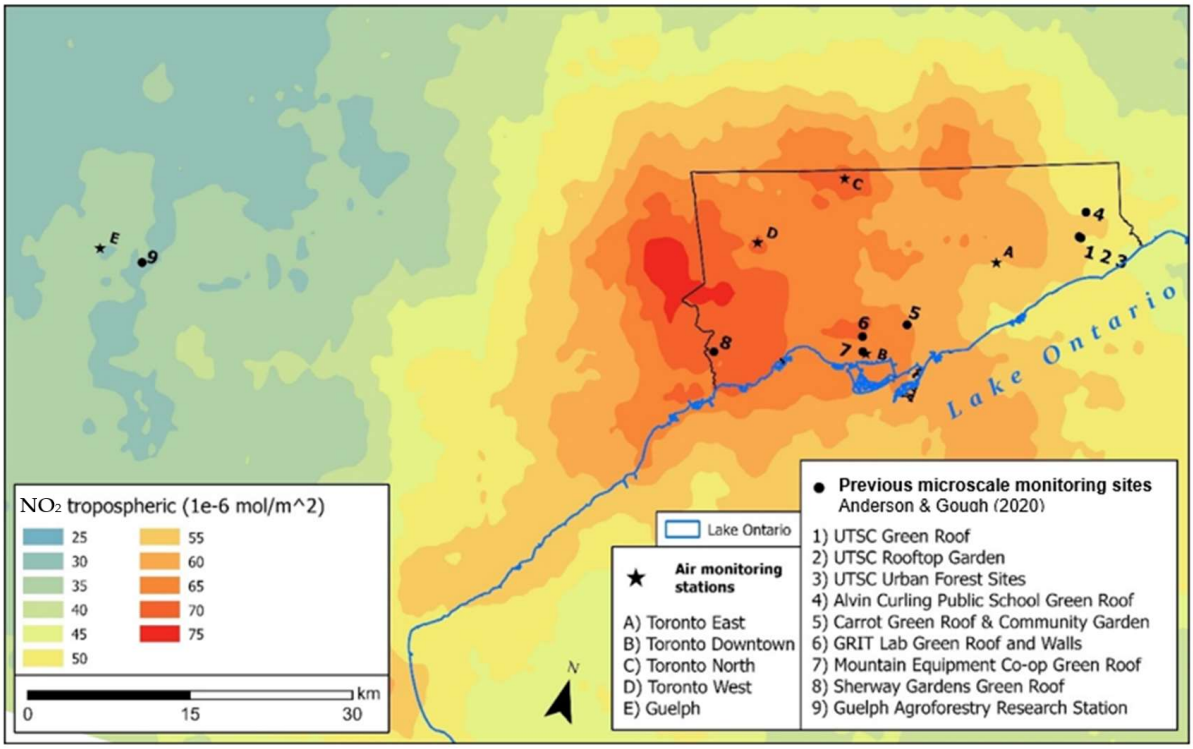

Figure 5. Spatial distribution of NO_2 tropospheric column mean from July to October 2018 [38].

There is a strong east/west gradient of nitrogen dioxide across the Greater Toronto Area as a result of higher distributions of urban vegetation and forestry and less industrial activity, in addition to the presence of a large urban forest at the east end of Toronto, Rouge National Urban Park. The park was formally created in 2011 and has been expanded since to consist of 79.1 square km. It is the largest urban park in North America and is largely forested and available to the public for hiking and camping.

As shown in Figure 6, there is a correlation between NDVI distribution and nitrogen dioxide concentrations. The mobile nature of nitrogen dioxide and the combination of sources and sinks that determine nitrogen concentrations, lead to a relatively low correlation of $R^2 = 0.14$. However, this is reflective of areas of high nitrogen dioxide concentrations linked to areas of low vegetation and biological productivity. It should also be noted that nitrogen dioxide is highly mobile (e.g., airborne) and prevailing winds tend to flow from the west in Southern Ontario, which can influence the location of pollutant concentrations.

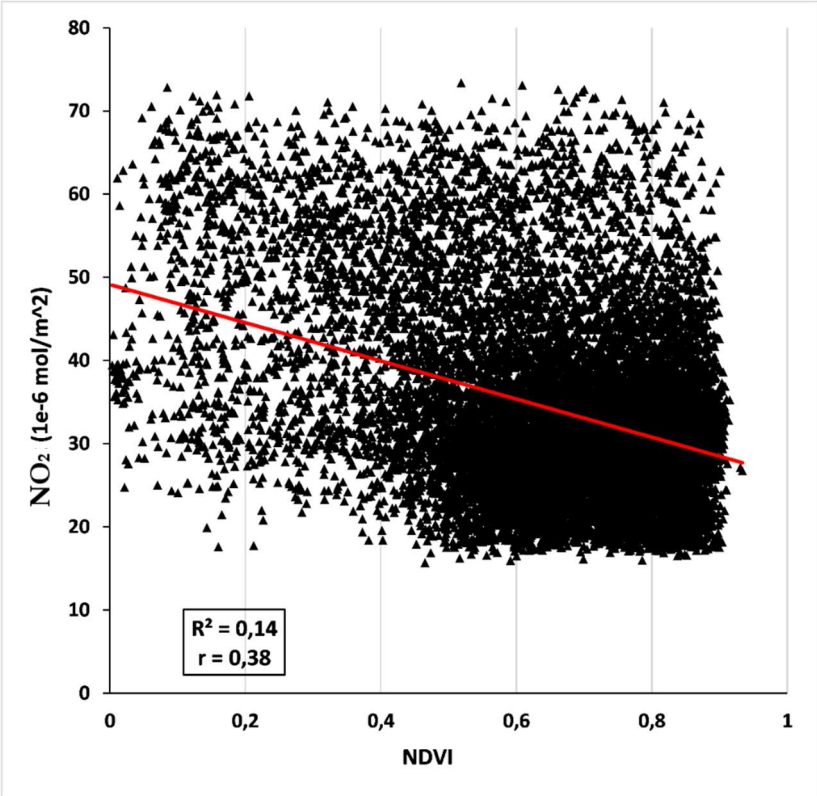

Figure 6. Scatter plot shows correlation between NDVI and nitrogen dioxide (NO_2) for all non-water pixels.

3.2. Air Monitoring Station Observations of Nitrogen Dioxide

Table 1 shows the monthly averaged nitrogen dioxide concentrations (ppb) from June to October of 2017 and 2018, coincident with the satellite data collection campaign, for the five provincial air monitoring stations (Figure 2). These values are qualitatively compared to the satellite observations of nitrogen dioxide shown in Figure 5. The satellite observations of nitrogen dioxide are a column of integrated tropospheric measurements, whereas the air monitoring station data is a location (geographical and height) sampling of the atmosphere. The locations of the five air monitoring stations are indicated in both Figures 4 and 5. While 2017 was higher in nitrogen dioxide concentrations than 2018, the two years displayed the same spatial distribution as is indicated by the relative rankings of the five locations. For both years, the Guelph station had the lowest nitrogen dioxide values and Toronto West had the highest nitrogen dioxide concentrations, followed by the Toronto Downtown station. Of the four Toronto station locations, Toronto North had the lowest values of nitrogen

dioxide, followed by Toronto East. This pattern is consistent with the satellite-based data in Figure 5 with the possible exception of the Toronto North station, which shows higher values for the satellite-based data than Toronto East station. As the two data sets are not measuring nitrogen dioxide in the same fashion (the satellite value is a vertical column average of the tropospheric nitrogen dioxide and the air monitoring stations are a sampling at one height), this may account for the discrepancy. The peak value at the Toronto West station appears well-linked to the large, localized area of nitrogen dioxide adjacent and upstream (west) of the Toronto West station, in an area of low NDVI distribution. The much lower values at the Guelph station are consistent with the satellite data and an area of high NDVI productivity as well as lower industrialization. In this respect, the Guelph site can be considered as a "control" site for the other four more urbanized sites in the Toronto area.

Table 1. NO_2 (ppb) measured at five provincial air monitoring stations from June to October in 2017 and 2018.

Year/Month	Nitrogen Dioxide (NO_2) Values (ppb) by Station				
2017	**Toronto East**	**Toronto North**	**Toronto Downtown**	**Toronto West**	**Guelph**
June	10.48	7.99	10.92	12.57	3.80
July	9.28	7.20	10.78	11.83	3.28
August	9.31	7.81	11.06	12.32	4.04
September	13.07	10.56	14.00	15.67	5.77
October	11.14	10.80	12.63	15.49	6.20
Average NO_2	10.66	8.87	11.88	13.57	4.62
Ranking	3	4	2	1	5
Year/Month	**Nitrogen dioxide (NO_2) values (ppb) by station**				
2018	**Toronto East**	**Toronto North**	**Toronto Downtown**	**Toronto West**	**Guelph**
June	7.74	6.86	9.89	11.00	4.02
July	7.75	7.51	9.34	10.62	3.79
August	7.76	7.32	9.33	10.90	3.67
September	6.77	6.47	8.35	9.67	3.96
October	9.38	10.24	10.89	9.93	5.19
Average NO_2	7.88	7.68	9.56	10.42	4.13
Ranking	3	4	2	1	5

4. Discussion

The results of the two data collection campaigns demonstrate that green infrastructure has reduced nitrogen dioxide concentration. Analyses of the data collected to measure the potential of green infrastructure to reduce nitrogen dioxide concentrations is consistent with the hypothesis that green infrastructure can remediate air pollution in Southern Ontario, Canada, regardless of location, geography, or land-use type. The potential of green infrastructure to remediate air pollution is well-established in the literature [30–33,35–38,40,51,63,66,77–80]. In this work, we used these microscale results to provide both a source and sink lens rather than just a source lens to interpret the atmospheric distribution of nitrogen dioxide. The microscale results that demonstrate nitrogen dioxide uptake by various forms of green infrastructure enable us to interpret larger scale results not only from a source perspective, that is, emissions, industrial and vehicular, but also from a sequestering of pollutants perspective. Thus, a non-industrial area has not just a lack of emissions, but an active sequestering of pollutants such as nitrogen dioxide by the natural vegetation, and this provides a more nuanced lens to interpret the large-scale, satellite data.

Thus, the two data analyses utilized remote sensing and stationary air monitoring observations to assess the potential of green infrastructure to reduce nitrogen dioxide concentrations at the coarser mesoscale and neighbourhood levels. The analysis of the remote sensing data underscores the linkages between high nitrogen dioxide concentrations and low NDVI distribution that can be clearly seen in the area just west of Toronto and the Toronto West air monitoring station. The analysis of the stationary air monitoring data from the Toronto West station confirms this finding with the highest recorded nitrogen dioxide levels of all five provincial air monitoring stations, which was consistent for both 2017 and 2018 and more generally as found in [85]. This is indicative of persistence behaviour that is illustrated by the 2018 satellite data results. The location of this station is reflective of the local urban morphology that includes major transportation arteries in an industrial section of the city. Land use is a significant factor in emissions of nitrogen dioxide. As illustrated in Figures 7 and 8, these land use maps show a large industrial zone (classified as 'employment' in Figure 7 and 'commercial/industrial' in Figure 8) that stretches from the west end of the city of Toronto across into the region of Peel (located immediately west of Toronto). We also note the substantially lower values for the Guelph site (Table 1), which in some respects serves as a "control site" for comparison to the highly industrialized Toronto area.

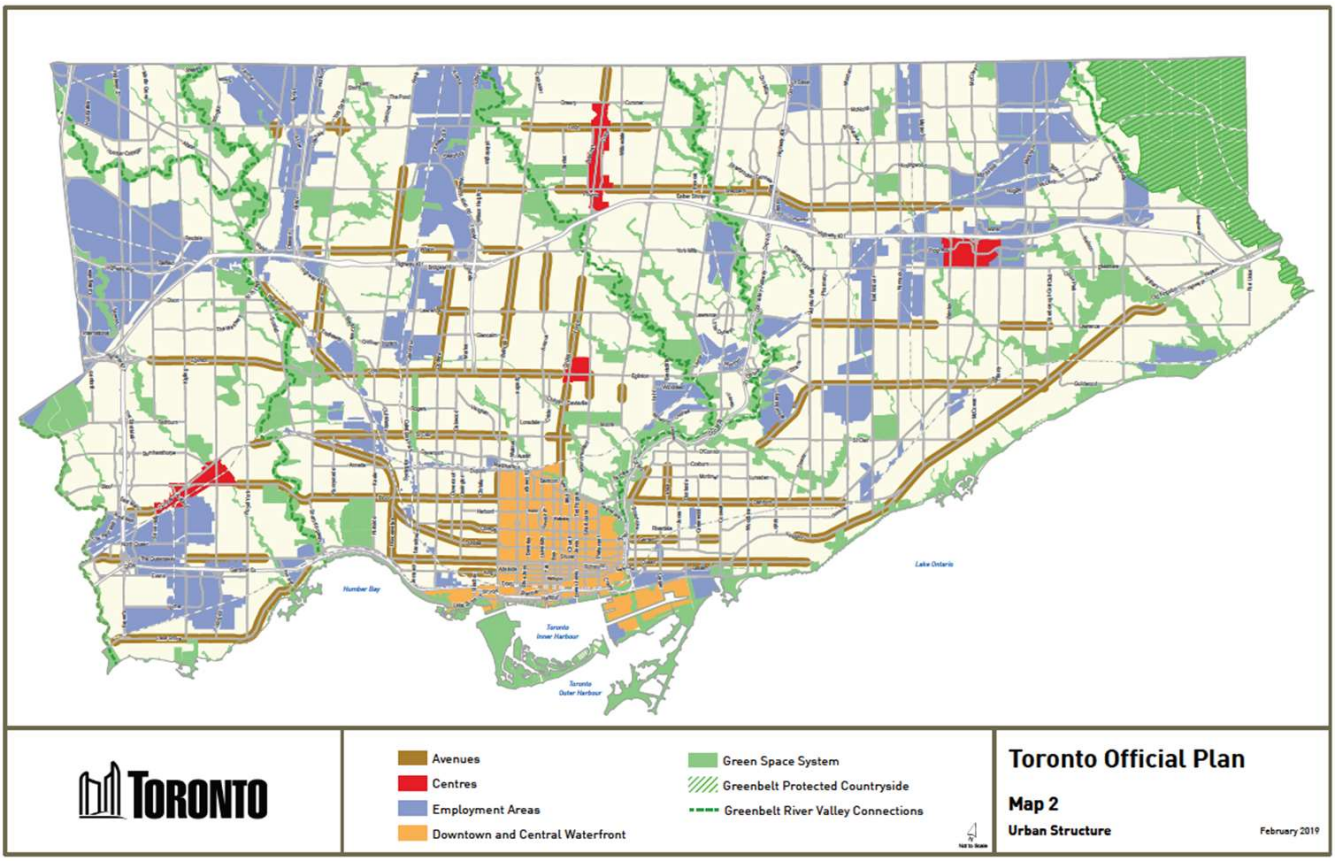

Figure 7. Map of land use designations in the city of Toronto (Source: City of Toronto, 2019).

This large, industrialized zone corresponds with the areas of low NDVI distribution (Figure 4) and higher nitrogen dioxide concentrations (Figure 5). Similarly, the 'employment zones' illustrated in Figure 9, correspond with the areas of lower NDVI distribution (Figure 4) and higher nitrogen dioxide concentrations (Figure 5) across the province. As illustrated in Figure 9, Guelph is a small, peri-urban municipality located in a largely rural area with low levels of industrial land use. This land use pattern is well-reflected in the higher NDVI distribution (Figure 4) and lower nitrogen dioxide concentrations (Figure 5).

Analysis of the stationary air monitoring data for the Guelph station also confirms this finding with the lowest recorded levels of nitrogen dioxide of the five provincial air monitoring stations. This is reflective of the local morphology of the Guelph air monitoring station, which is situated at the edge of a large park in a residential neighbourhood.

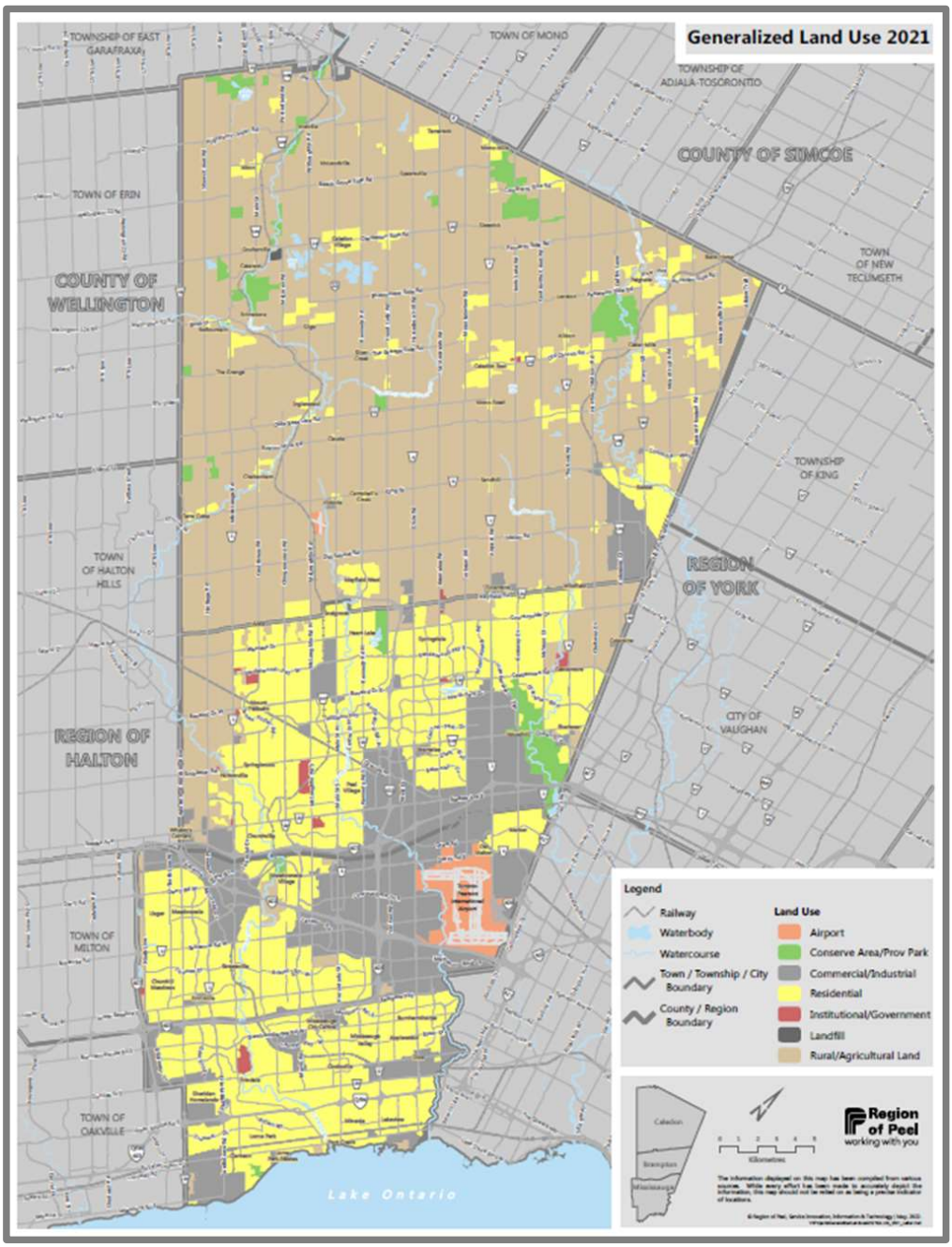

Figure 8. Map of land use designations in the Region of Peel (Source: Region of Peel, 2022).

Additionally, the designated 'employment areas' across the city of Toronto in Figure 9 depict industrial zones that correspond with areas of lower NDVI distribution (Figure 4) and higher nitrogen dioxide concentrations (Figure 5). Proximity to major transportation arteries provides additional and diffuse sources of nitrogen dioxide that contribute to its wider dispersal. Observations gained from the Landsat-8 satellite affirm that green infrastructure reduces nitrogen dioxide concentrations through high NDVI distribution of trees and dense vegetation at the neighbourhood level. This is consistent with the

microscale findings [35–38] that demonstrate multiple applications of green infrastructure from trees to green roofs, can reduce nitrogen dioxide concentrations. At the mesoscale, results show there is a link between compact, built-up, industrialized areas and higher nitrogen dioxide levels in Southern Ontario, Canada.

Figure 9. Map of provincially significant employment zones (shaded purple areas) in the province of Ontario (Source: Government of Ontario, 2020).

This work also provided an opportunity to explore a more nuanced source/sink framework for understanding nitrogen dioxide concentrations rather than examining it from an emissions (source) perspective solely. The regions of relatively lower nitrogen dioxide corresponded to sink regions characterized by natural vegetation (high NDVI). Thus, the results of the microscale analysis [35–38] inform how to interpret coarser scale observations.

Green infrastructure provides a multi-faceted strategy to remediate air pollution. Multiple applications of green infrastructure can significantly reduce air pollutant concentrations of nitrogen dioxide in urbanized and industrial settings, as evidenced in this study. Because there are different applications of green infrastructure with potential to improve air quality, the question emerges as to the nature of the most appropriate solution. While trees demonstrate peak uptake of air pollutants, combined applications of green infrastructure such as green roofs and walls, in addition to urban trees and shrubs, can be beneficial because they have fewer space requirements than conventional forests or woodlots, making them an ideal strategy to remediate point source air pollution in industrialized areas [80]. Additionally, continuity of form and size impact performance of tree planting strategies [35,74,79]. For example, a single tree is less effective in reducing air pollution than an urban forest. Due to their roadside proximity, hedgerows can be an effective alternative to filter particulate matter and reduce traffic-related air pollution in street canyons [60,67,74,78], while large scale green roof implementation and green walls can reduce air pollutant concentrations in urbanized settings [57,65,67,75,76]. When implementing green infrastructure applications to remediate air quality, streetscape geometry and orientation, configuration of the application, and wind flows must be considered to maximize efficacy [35,60,67,77,81].

This study presents a unique methodology for evaluating the remediation effect of NbS on air pollution and the prioritizing of neighbourhoods for green infrastructure implementation. This information can be valuable for the development of air quality remediation plans at both the site and neighbourhood levels. Future research areas of interest include: (1) undertaking a similar set of field studies over a multi-year period to incorporate seasonal variation; and (2) conducting a regional comparison to evaluate the potential of NbS to reduce air pollution across different morphologies and land use zones.

5. Conclusions

This work examined the following three research questions:

(1) Is there a measurable nature-based remediation effect in tropospheric nitrogen dioxide concentrations using a range of green infrastructure applications across different morphologies in Ontario, Canada, regardless of location, geography, or land use type?
(2) Are the nature-based remediation effects of green infrastructure on nitrogen dioxide concentrations visible by satellite imagery?
(3) Do parts of Ontario, Canada have higher concentrations of nitrogen dioxide due to the density of built-up surfaces or proximity to point sources?

Using the collective work of [35–38], which showed at the microscale the remediative effect of green infrastructure of a range of types on sequestering air pollutants, the results of this study, answer the first of the research questions in the affirmative and support the notion of green infrastructure as an atmospheric pollutant cleanser using nitrogen dioxide as a case study at both the neighbourhood level and mesoscales in Ontario, Canada. At the mesoscale, answering the second question, remote sensing, as well as stationary air monitoring, support the hypothesis that green infrastructure can reduce nitrogen dioxide concentrations through high NDVI distribution of trees and dense vegetation at the neighbourhood level, consistent with the findings of a microscale field campaign [38] and other similar microscale studies [35–37]. Additionally, as presented in detail in the Discussion, we answer the third research question and show there is an unsurprising link between compact, built-up, industrialized areas and higher nitrogen dioxide levels at the mesoscale, particularly notable to the west of the city of Toronto. This work explored a more nuanced source/sink framing for understanding nitrogen dioxide spatial distribution rather than examining it solely from an emissions' source perspective. The regions of relatively lower nitrogen dioxide corresponded to sink regions characterized by natural vegetation (high NDVI), indicative of the green infrastructure of urban vegetation and forestry.

While the nature-based remediation effect may vary across individual applications of green infrastructure, it can effectively reduce air pollution by optimizing the built environment, and leveraging the co-benefits of temperature regulation, stormwater management, biodiversity and pollinator support, and enhanced food security. In addition to air pollution abatement, the broad application of green infrastructure can increase climate resilience, providing a multi-faceted nature-based solution to the challenges presented by different urban, suburban, and peri-urban environments.

Author Contributions: V.A.: Conceptualization, Investigation, Formal analysis, Writing—original draft, Writing—review & editing. M.Z.: Investigation, Formal analysis. W.A.G.: Conceptualization, Formal analysis, Writing—review & editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Sciences and Engineering Research Council of Canada (NSERC) through W.A.G's Grant RGPIN-2018-06801.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors wish to express their appreciation to Next Level Storm Water Management, Mountain Equipment Co-op, the Seeds of Hope Foundation, and the University of Guelph Agroforestry Research Station for providing site access.

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

References

1. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. (Eds.) *Nature-Based Solutions to Address Global Societal Challenges*; IUCN: Gland, Switzerland, 2016; xiii + 97p, ISBN 978-2-8317-1812-5. [CrossRef]
2. Cohen-Shacham, E.; Andrade, A.; Dalton, J.; Dudley, N.; Jones, M.; Kumar, C.; Maginnis, S.; Maynard, S.; Nelson, C.R.; Renaud, F.G.; et al. Core principles for successfully implementing and upscaling Nature-based Solutions. *Environ. Sci. Policy* **2019**, *98*, 20–29. [CrossRef]
3. Seddon, N.; Chausson, A.; Berry, P.; Girardin, C.A.J.; Smith, A.; Turner, B. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philos. Trans. R. Soc. B Biol. Sci.* **2020**, *375*, 20190120. [CrossRef]
4. Revi; Satterthwaite, D.E.; Aragón-Durand, F.; Corfee-Morlot, J.; Kiunsi, R.B.R.; Pelling, M.; Roberts, D.C.; Solecki, W. Urban areas. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 535–612.
5. Stocker, T.F.; Qin, D.; Plattner, G.-K.; Alexander, L.V.; Allen, S.K.; Bindoff, N.L.; Bréon, F.-M.; Church, J.A.; Cubasch, U.; Emori, S.; et al. Technical Summary. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
6. Fiore, A.M.; Naik, V.; Leibensperger, E.M. Air Quality and Climate Connections. *J. Air Waste Manag. Assoc.* **2015**, *65*, 645–685. [CrossRef] [PubMed]
7. Ordóñez, C.; Mathis, H.; Furger, M.; Henne, S.; Hüglin, C.; Staehelin, J.; Prévôt, A.S.H. Changes of daily surface ozone maxima in Switzerland in all seasons from 1992 to 2002 and discussion of summer 2003. *Atmos. Meas. Tech.* **2005**, *5*, 1187–1203. [CrossRef]
8. Tressol, M.; Ordonez, C.; Zbinden, R.; Brioude, J.; Thouret, V.; Mari, C.; Nedelec, P.; Cammas, J.-P.; Smit, H.; Patz, H.-W.; et al. Air pollution during the 2003 European heat wave as seen by MOZAIC airliners. *Atmos. Meas. Tech.* **2008**, *8*, 2133–2150. [CrossRef]
9. Jacob, D.J.; Winner, D.A. Effect of climate change on air quality. *Atmos. Environ.* **2009**, *43*, 51–63. [CrossRef]
10. Weaver, C.P.; Liang, X.-Z.; Zhu, J.; Adams, P.J.; Amar, P.; Avise, J.; Caughey, M.; Chen, J.; Cohen, R.C.; Cooter, E.; et al. A Preliminary Synthesis of Modeled Climate Change Impacts on U.S. Regional Ozone Concentrations. *Bull. Am. Meteorol. Soc.* **2009**, *90*, 1843–1864. [CrossRef]
11. Vieno, M.; Dore, A.J.; Stevenson, D.S.; Doherty, R.; Heal, M.R.; Reis, S.; Hallsworth, S.; Tarrason, L.; Wind, P.; Fowler, D.; et al. Modelling surface ozone during the 2003 heat-wave in the UK. *Atmos. Meas. Tech.* **2010**, *10*, 7963–7978. [CrossRef]
12. Lucon, O.; Ürge-Vorsatz, D.; Ahmed, A.Z.; Akbari, H.; Bertoldi, P.; Cabeza, L.F.; Eyre, N.; Gadgil, A.; Harvey, L.D.D.; Jiang, Y.; et al. Buildings. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
13. Smith, P.; Bustamante, M.; Ahammad, H.; Clark, H.; Dong, H.; Elsiddig, E.A.; Haberl, H.; Harper, R.; House, J.; Jafari, M.; et al. Agriculture, Forestry and Other Land Use (AFOLU). In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
14. Office of the Auditor General of Ontario (OAGO). Value for Money Audit: Reducing Greenhouse Gas Emissions from Energy Use in Buildings. 2020. Available online: https://www.auditor.on.ca/en/content/annualreports/arreports/en20/ENV_reducinggreenhousegasemissions_en20.pdf (accessed on 15 June 2022).
15. Fischedick, M.; Roy, J.; Abdel-Aziz, A.; Acquaye, A.; Allwood, J.M.; Ceron, J.-P.; Geng, Y.; Kheshgi, H.; Lanza, A.; Perczyk, D.; et al. Industry. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
16. Sims, R.; Schaeffer, R.; Creutzig, F.; Cruz-Núñez, X.; D'Agosto, M.; Dimitriu, D.; Meza, M.J.F.; Fulton, L.; Kobayashi, S.; Lah, O.; et al. Transport. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.

17. Hassan, N.A.; Hashim, Z.; Hashim, J.H. Impact of Climate Change on Air Quality and Public Health in Urban Areas. *Asia Pac. J. Public Health* **2016**, *28* (Suppl. S2), 38S–48S. [CrossRef] [PubMed]
18. Restrepo, C.E. Nitrogen Dioxide, Greenhouse Gas Emissions and Transportation in Urban Areas: Lessons from the Covid-19 Pandemic. *Front. Environ. Sci.* **2021**, *9*, 689985. [CrossRef]
19. Toronto Public Health. Air Pollution Burden of Illness in Toronto—Summary Report. 2000. Available online: https://www.toronto.ca/legdocs/2000/agendas/council/cc/cc000607/hl4rpt/cl001.pdf (accessed on 15 June 2022).
20. Ontario Agency for Health Protection and Promotion (Public Health Ontario—PHO); Kim, J.H.; Copes, R. *Case Study: Health Effects of Traffic Related Air Pollution in a Small Community*; Queen's Printer for Ontario: Toronto, ON, Canada, 2015; Available online: https://www.publichealthontario.ca/-/media/documents/c/2015/case-study-traffic-pollution.pdf?sc_lang=en (accessed on 15 June 2022).
21. Government of Canada (GOC). Human Health Risk Assessment for Ambient Nitrogen Dioxide. 2016. Available online: https://www.canada.ca/en/health-canada/services/publications/healthy-living/human-health-risk-assessment-ambient-nitrogen-dioxide.html (accessed on 15 June 2022).
22. World Health Organization. Ambient (Outdoor) Air Pollution Fact Sheet. 2021. Available online: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (accessed on 15 June 2022).
23. Tao, Y.; Mi, S.; Zhou, S.; Wang, S.; Xie, X. Air pollution and hospital admissions for respiratory diseases in Lanzhou, China. *Environ. Pollut.* **2014**, *185*, 196–201. [CrossRef]
24. Hamra, G.B.; Laden, F.; Cohen, A.J.; Raaschou-Nielsen, O.; Brauer, M.; Loomis, D. Lung Cancer and Exposure to Nitrogen Dioxide and Traffic: A Systematic Review and Meta-Analysis. *Environ. Health Perspect.* **2015**, *123*, 1107–1112. [CrossRef]
25. Pannullo, F.; Lee, D.; Neal, L.; Dalvi, M.; Agnew, P.; O'Connor, F.M.; Mukhopadhyay, S.; Sahu, S.; Sarran, C. Quantifying the impact of current and future concentrations of air pollutants on respiratory disease risk in England. *Environ. Health* **2017**, *16*, 29. [CrossRef] [PubMed]
26. Anenberg, S.C.; Henze, D.K.; Tinney, V.; Kinney, P.L.; Raich, W.; Fann, N.; Malley, C.S.; Roman, H.; Lamsal, L.; Duncan, B.; et al. Estimates of the Global Burden of Ambient PM2.5, Ozone, and NO_2 on Asthma Incidence and Emergency Room Visits. *Environ. Health Perspect.* **2018**, *126*, 107004. [CrossRef] [PubMed]
27. Achakulwisut, P.; Brauer, M.; Hystad, P.; Anenberg, S.C. Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: Estimates from global datasets. *Lancet Planet. Health* **2019**, *3*, e166–e178. [CrossRef]
28. Zeng, W.; Zhao, H.; Liu, R.; Yan, W.; Qiu, Y.; Yang, F.; Shu, C.; Zhan, Y. Association between NO_2 cumulative exposure and influenza prevalence in mountainous regions: A case study from southwest China. *Environ. Res.* **2020**, *189*, 109926. [CrossRef] [PubMed]
29. Alexandri, E.; Jones, P. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Build. Environ.* **2006**, *43*, 480–493. [CrossRef]
30. Berardi, U.; AmirHosein, G.H.; Ali, G. State-of-the-art analysis of the environmental benefits of green roofs. *Appl. Energy* **2014**, *115*, 411–428. [CrossRef]
31. Feng, H.; Hewage, K. Lifecycle assessment of living walls: Air purification and energy performance. *J. Clean. Prod.* **2014**, *69*, 91–99. [CrossRef]
32. Yang, J.; Yu, Q.; Gong, P. Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environ.* **2008**, *42*, 7266–7273. [CrossRef]
33. Baik, J.-J.; Kwak, K.-H.; Park, S.-B.; Ryu, Y.-H. Effects of building roof greening on air quality in street canyons. *Atmospheric Environ.* **2012**, *61*, 48–55. [CrossRef]
34. Bowler, D.E.; Buyung-Ali, L.; Knight, T.M.; Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landsc. Urban Plan.* **2010**, *97*, 147–155. [CrossRef]
35. Nowak, D.J.; Hirabayashi, S.; Doyle, M.; McGovern, M.; Pasher, J. Air pollution removal by urban forests in Canada and its effect on air quality and human health. *Urban For. Urban Green.* **2018**, *29*, 40–48. [CrossRef]
36. Sicard, P.; Agathokleous, E.; Araminiene, V.; Carrari, E.; Hoshika, Y.; De Marco, A.; Paoletti, E. Should we see urban trees as effective solutions to reduce increasing ozone levels in cities? *Environ. Pollut.* **2018**, *243*, 163–176. [CrossRef]
37. Gourdji, S. Review of plants to mitigate particulate matter, ozone as well as nitrogen dioxide air pollutants and applicable recommendations for green roofs in Montreal, Quebec. *Environ. Pollut.* **2018**, *241*, 378–387. [CrossRef] [PubMed]
38. Anderson, V.; Gough, W.A. Evaluating the potential of nature-based solutions to reduce ozone, nitrogen dioxide, and carbon dioxide through a multi-type green infrastructure study in Ontario, Canada. *City Environ. Interactions* **2020**, *6*, 100043. [CrossRef]
39. Anderson, V.; Gough, W.A. Nature-based cooling potential: A multi-type green infrastructure evaluation in Toronto, Ontario, Canada. *Int. J. Biometeorol.* **2021**, *66*, 397–410. [CrossRef]
40. Anderson, V.; Gough, W.A. Nature-Based Resilience: A Multi-Type Evaluation of Productive Green Infrastructure in Agricultural Settings in Ontario, Canada. *Atmosphere* **2021**, *12*, 1183. [CrossRef]
41. Anderson, V.; Gough, W.A.; Zgela, M.; Milosevic, D.; Dunjic, J. Lowering the Temperature to Increase Heat Equity: A Multi-Scale Evaluation of Nature-Based Solutions in Toronto, Ontario, Canada. *Atmosphere* **2022**, *13*, 1027. [CrossRef]
42. Li, J.-F.; Wai, O.W.; Li, Y.; Zhan, J.-M.; Ho, Y.A.; Li, J.; Lam, E. Effect of green roof on ambient CO2 concentration. *Build. Environ.* **2010**, *45*, 2644–2651. [CrossRef]

43. Marchi, M.; Pulselli, R.M.; Marchettini, N.; Pulselli, F.M.; Bastianoni, S. Carbon dioxide sequestration model of a vertical greenery system. *Ecol. Model.* **2014**, *306*, 46–56. [CrossRef]
44. Hall, J.M.; Handley, J.F.; Ennos, A.R. The potential of tree planting to climate-proof high density residential areas in Manchester, UK. *Landsc. Urban Plan.* **2011**, *104*, 410–417. [CrossRef]
45. Velasco, E.; Roth, M.; Norford, L.; Molina, L.T. Does urban vegetation enhance carbon sequestration? *Landsc. Urban Plan.* **2016**, *148*, 99–107. [CrossRef]
46. Fargione, J.E.; Bassett, S.; Boucher, T.; Bridgham, S.D.; Conant, R.T.; Cook-Patton, S.C.; Ellis, P.W.; Falcucci, A.; Fourqurean, J.W.; Gopalakrishna, T.; et al. Natural climate solutions for the United States. *Sci. Adv.* **2018**, *4*, eaat1869. [CrossRef] [PubMed]
47. Graves, R.A.; Haugo, R.D.; Holz, A.; Nielsen-Pincus, M.; Jones, A.; Kellogg, B.; Macdonald, C.; Popper, K.; Schindel, M. Potential greenhouse gas reductions from Natural Climate Solutions in Oregon, USA. *PLoS ONE* **2020**, *15*, e0230424. [CrossRef]
48. Thornbush, M. Urban agriculture in the transition to low carbon cities through urban greening. *AIMS Environ. Sci.* **2015**, *2*, 852–867. [CrossRef]
49. Anderson, V.; Gough, W.A. A Typology of Nature-Based Solutions for Sustainable Development: An Analysis of Form, Function, Nomenclature, and Associated Applications. *Land* **2022**, *11*, 1072. [CrossRef]
50. Anderson, V.; Gough, W.A. Harnessing the Four Horsemen of Climate Change: A Framework for Deep Resilience, Decarbonization, and Planetary Health in Ontario, Canada. *Sustainability* **2021**, *13*, 379. [CrossRef]
51. Anderson, V.; Gough, W.A.; Agic, B. Nature-Based Equity: An Assessment of the Public Health Impacts of Green Infrastructure in Ontario Canada. *Int. J. Environ. Res. Public Health* **2021**, *18*, 5763. [CrossRef]
52. Thevathasan, N.V.; Gordon, A.M. Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada. *Agrofor. Syst.* **2004**, *61*, 257–268.
53. Wotherspoon, A.; Thevathasan, N.V.; Gordon, A.M.; Voroney, R.P. Carbon sequestration potential of five tree species in a 25-year-old temperate tree-based intercropping system in southern Ontario, Canada. *Agrofor. Syst.* **2014**, *88*, 631–643. [CrossRef]
54. Nowak, D.J.; Crane, D.E.; Stevens, J.C. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Green.* **2006**, *4*, 115–123. [CrossRef]
55. Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kaźmierczak, A.; Niemela, J.; James, P. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landsc. Urban Plan.* **2007**, *81*, 167–178. [CrossRef]
56. Susca, T.; Gaffin, S.R.; Dell'Osso, G.R. Positive effects of vegetation: Urban heat island and green roofs. *Environ. Pollut.* **2011**, *159*, 2119–2126. [CrossRef]
57. Speak, A.F.; Rothwell, J.J.; Lindley, S.J.; Smith, C.L. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. *Atmos. Environ.* **2012**, *61*, 283–293. [CrossRef]
58. Kessler, R. Urban Gardening: Managing the Risks of Contaminated Soil. *Environ. Health Perspect.* **2013**, *121*, A326–A333. [CrossRef] [PubMed]
59. Morakinyo, T.E.; Lam, Y.F.; Hao, S. Evaluating the role of green infrastructures on near-road pollutant dispersion and removal: Modelling and measurement. *J. Environ. Manag.* **2016**, *182*, 595–605. [CrossRef]
60. Abhijith, K.; Kumar, P.; Gallagher, J.; McNabola, A.; Baldauf, R.; Pilla, F.; Broderick, B.; Di Sabatino, S.; Pulvirenti, B. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments—A review. *Atmos. Environ.* **2017**, *162*, 71–86. [CrossRef]
61. Tan, C.L.; Wong, N.H.; Jusuf, S.K. Effects of vertical greenery on mean radiant temperature in the tropical urban environment. *Landsc. Urban Plan.* **2014**, *127*, 52–64. [CrossRef]
62. Chen, D.; Wang, X.; Thatcher, M.; Barnett, G.; Kachenko, A.; Prince, R. Urban vegetation for reducing heat related mortality. *Environ. Pollut.* **2014**, *192*, 275–284. [CrossRef]
63. King, K.L.; Johnson, S.; Kheirbek, I.; Lu, J.W.; Matte, T. Differences in magnitude and spatial distribution of urban forest pollution deposition rates, air pollution emissions, and ambient neighborhood air quality in New York City. *Landsc. Urban Plan.* **2014**, *128*, 14–22. [CrossRef]
64. Rao, M.; George, L.A.; Rosenstiel, T.N.; Shandas, V.; Dinno, A. Assessing the relationship among urban trees, nitrogen dioxide, and respiratory health. *Environ. Pollut.* **2014**, *194*, 96–104. [CrossRef] [PubMed]
65. Kleerekoper, L.; Van Esch, M.; Salcedo, T.B. How to make a city climate-proof, addressing the urban heat island effect. *Resour. Conserv. Recycl.* **2012**, *64*, 30–38. [CrossRef]
66. Weber, F.; Kowarik, I.; Säumel, I. Herbaceous plants as filters: Immobilization of particulates along urban street corridors. *Environ. Pollut.* **2014**, *186*, 234–240. [CrossRef] [PubMed]
67. Abjihith, K.V.; Kumar, P. Field investigations for evaluating green infrastructure effects on air quality in open-road conditions. *Atmos. Environ.* **2019**, *201*, 132–147. [CrossRef]
68. Anderson, V.; Gough, W.A. Form, Function, and Nomenclature: Deconstructing Green Infrastructure and its Role in a Changing Climate. In *Climate Change and Extreme Events*; Fares, A., Ed.; Elsevier: Maryland Heights, MO, USA, 2021; ISBN U1104201903351.
69. Voskamp, I.M.; Van de Ven, F.H.M. Planning support system for climate change: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. *Build. Environ.* **2014**, *83*, 159–167. [CrossRef]
70. Anderson, V. Deep Adaptation: A Framework for Climate Resilience, Decarbonization and Planetary Health in Ontario. Ph.D. Thesis, University of Toronto, Toronto, Ontario, 2018. Available online: https://tspace.library.utoronto.ca/ (accessed on 15 June 2022).

71. Lin, B.B.; Philpott, S.M.; Jha, S. The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic Appl. Ecol.* **2015**, *16*, 189–201. [CrossRef]
72. Thornbush, M. *Vehicular Air Pollution and Urban Sustainability: An Assessment from Central Oxford, UK*; Springer Briefs in Geography; Springer: Cham, Switzerland, 2015.
73. Tan, P.Y.; Sia, A. A pilot green roof research project in Singapore. In Proceedings of the Third Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show, Washington, DC, USA, 4–6 May 2005.
74. Vos, P.E.J.; Maiheu, B.; Vankerkom, J.; Janssen, S. Improving local air quality in cities: To tree or not to tree? *Environ. Pollut.* **2013**, *183*, 113–122. [CrossRef]
75. Joshi, S.V.; Ghosh, S. On the air cleansing efficiency of an extended green wall: A CFD analysis of mechanistic details of transport processes. *J. Theor. Biol.* **2014**, *361*, 101–110. [CrossRef]
76. Whittinghill, L.J.; Rowe, D.B.; Schutzki, R.; Cregg, B.M. Quantifying carbon sequestration of various green roof and ornamental landscape systems. *Landsc. Urban Plan.* **2014**, *123*, 41–48. [CrossRef]
77. Janhäll, S. Review on urban vegetation and particle air pollution—Deposition and dispersion. *Atmos. Environ.* **2015**, *105*, 130–137. [CrossRef]
78. Gromke, C.; Jamarkattel, N.; Ruck, B. Influence of roadside hedgerows on air quality in urban street canyons. *Atmos. Environ.* **2016**, *139*, 75–86. [CrossRef]
79. Bottalico, F.; Chirici, G.; Giannetti, F.; De Marco, A.; Nocentini, S.; Paoletti, E.; Salbitano, F.; Sanesi, G.; Serenelli, C.; Travaglini, D. Air Pollution Removal by Green Infrastructures and Urban Forests in the City of Florence. *Agric. Agric. Sci. Procedia* **2016**, *8*, 243–251. [CrossRef]
80. Jayasooriya, V.; Ng, A.; Muthukumaran, S.; Perera, B. Green infrastructure practices for improvement of urban air quality. *Urban For. Urban Green.* **2017**, *21*, 34–47. [CrossRef]
81. Taleghani, M.; Clark, A.; Swan, W.; Mohegh, A. Air pollution in a microclimate; the impact of different green barriers on the dispersion. *Sci. Total. Environ.* **2020**, *711*, 134649. [CrossRef]
82. Environmental Protection Agency (EPA). EPA Combines Expertise with New Zealand Company to Advance Air Sensor Technologies. 2019. Available online: https://www.epa.gov/sciencematters/epa-combines-expertise-new-zealand-company-advance-air-sensor-technologies (accessed on 15 June 2022).
83. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ.* **2017**, *202*, 18–27. [CrossRef]
84. Carlson, T.N.; Ripley, D.A. On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sens. Environ.* **1997**, *62*, 241–252. [CrossRef]
85. Gough, W.A.; Anderson, V. Changing Air Quality and the Ozone Weekend Effect during the COVID-19 Pandemic in Toronto, Ontario, Canada. *Climate* **2022**, *10*, 41. [CrossRef]