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Analyzing Air Pollutant Reduction Possibilities in the City of Zagreb

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Abstract: This paper aims to present possible areas to plant different vegetation types near traffic jams to reduce air pollution in the capital of Croatia, the city of Zagreb. Based on main traffic road and random forest machine learning using WorldView-2 European cities data, potential areas are established. It is seen that, based on a 10 m buffer, there is a possible planting area of more than 220,000 square meters, and based on 15 m buffer, there is a possible planting area of more than 410,000 square meters. The proposed plants are *Viburnum lucidum*, *Photinia x fraseri*, *Euonymus japonicus*, *Tilia cordata*, *Aesculus hippocastanum*, *Pinus* sp., *Taxus baccata*, *Populus alba*, *Quercus robur*, *Betula pendula,* which are characteristic for urban areas in Croatia. The planting of proposed trees may result in an increase of 3–5% in the total trees in the city of Zagreb. Although similar research has been published, this paper presents novelty findings from combined machine learning methods for defining green urban areas. Additionally, this paper presents original results for this region.

Keywords: air pollution; random forest; city of Zagreb; WorldView-2 data; green urban areas; road traffic

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1. Introduction

Polluted air in urban areas causes a myriad of health problems to the population and creates a need to address them on a global scale. Zagreb, the capital of Croatia, is a city with some significant air pollution issues. During colder months, pollution levels are considerable and require projects and interventions in the public space to bring pollutant levels down and improve air quality. Air pollution in Zagreb can be attributed to couple of causes, such are factories, industrial zones, and power plants. Coal and diesel are still the main fuels used in energy production and heavy machinery utilization. Other than that, factories, depending on the types of products they make, can be a source of numerous novel chemicals, such as dioxins, furans, microplastics, etc. In densely populated urban areas, one cannot overlook vehicular emissions [1]. There is a high amount of smoke and fumes released from personal vehicles used for everyday commuting and from heavy duty vehicles, such as trucks and lorries transporting goods and industrial items [1]. To obtain a clearer picture, one can simply look at number of produced cars. In 1999, around 39 million cars were produced [2]. Each year, this number increases, and in 2020, around 70 million cars were produced [2,3]. In Croatia, in last 5 years, there was an increase of 15% in registered passenger cars [4]. Approximately 100,000 motor vehicles are used in Zagreb each day. One way in which this problem can be partially alleviated is a ban on driving in the city center or a ban on certain days (e.g., Saturday and Sunday) [5]. Although this has a positive effect, main roads must remain open for traffic. Traffic jams are defined by a geoportal report on the city of Zagreb [6]. Traffic jams are detected and incorporated in this work as abstract-level, since the highest pollution comes near roads with traffic jams. Another possible solution is to use more environmentally friendly means of transport, such as electric cars, bicycles, or public transport, or to try and stop the pollution from spreading further away from the most frequenting corridors by use of green infrastructure. Roadside green infrastructure can be applied with minimal required changes to existing urban environments [7]. Targeted, well-planned and evidence-based space interventions can promote the health of urban residents [8].

According to [9], the term "green infrastructure" can relate to trees and vegetation that provide ecological benefits in urban areas or manmade structures, such as sustainable urban drainage systems. A proper choice of green infrastructure design can have a positive effect on personal exposure to air pollutants and human health. Green infrastructure in urban areas can reduce vulnerability to heat waves and floods, aiding in climate change mitigation by increased carbon storage and lower pollution impacts. Urban vegetation can provide a significant improvement in air quality through the reduction in air pollutants [10]. When designing green barriers, one must consider context and differentiate between two typical urban environments, open road and street canyon, since poorly chosen types of vegetation can promote the dispersion of pollution by exerting further mechanical turbulence [11]. Barbano et al. (2020) [12] found that trees can substantially modify flow circulation and intensity. By breaking the canopy vortex into smaller eddies, a recirculation zone at the foot of the windward wall is created which can negatively impact local air quality. The fact that vegetation can have adverse effects on air quality and, as a result, pedestrian exposure, clearly shows that, in order to promote public health, exposure studies should be developed whenever a planning intervention is contemplated [13]. Other possible negative effects of green infrastructure, such as the emission of biological volatile organic compounds (bVOCs) or pollen, can be mitigated by careful and well-thought-through choices of species for planting. The highest scoring species according to the Urban Tree Air Quality Score are *Acer campestre*, *Acer platanoides*, *Alnus glutinosa*, *Betula pendula*, *Chamaecyparis lawsoniana*, *Crataegus monogyna*, *Larix decidua*, *Prunus laurocerasus* and *Pinus nigra* [14]. The fact that not all plant species are equally resistant to air pollution should also be taken into consideration. In contrary to other species that are quite resistant to air pollution, sensitive plants are negatively affected by it. As a result, picking the right plant species is crucial. The air pollution tolerance index (APTI) assesses how sensitive or tolerable plants are to pollution. Plant species can be categorized into numerous categories based on their anticipated performance index (API) value, which takes into account both APTI and different parameters, such as canopy structure, type of tree, economic value, etc. Air quality can be improved by using a plant species with a high API value [15]. The problem of pollen and possible allergies can be mitigated by choosing female cultivars or insect-pollinated species. A common misconception regarding urban greenery is that increasing the amount of vegetation linearly reduces ground-level pollutant concentrations. When deposition may be aided by retaining air near vegetation for extended periods of time, urban greenery is beneficial. Urban greenery can be successful in a variety of spaces, from a modest "green oasis," such as a bench surrounded by thick hedges, to a dense urban woodland [16]. Major European cities have recognized the importance of urban greenery and are undertaking projects to increase the number of areas planted with trees and shrubs. For example, in the French city of Nantes, which won the title of European Green Capital in 2013, 100% of the population lives within a 300 m to green space [17]. Zagreb, on the other hand, is one of the capital cities with the lowest amount of urban greenery per capita. The importance of greenery in the fight against climate change has also been recognized by the Croatian government, which has committed itself to planting one million trees a year by 2030.

One of the steps towards the supervision and better management of urban greenery in the city of Zagreb was made by establishing a digital database called the "Cadastre of Greenery". This online database is the result of cooperation between the City of Zagreb; Zrinjevac, a public firm in charge of Zagreb's urban greenery maintenance; and the company Apis. To establish this cadastre, all trees, flower beds, shrubs, lawns, baskets, and sports and children's playgrounds were systematized and inventoried. According to data provided by Zrinjevac, there are more than 160,000 trees and shrubs in the city area. The dominant species are birch (*Betula pendula*), maple (*Acer platanoides*), platana (*Platana x acerifolia*), sycamore maple (*Acer pseudoplatanus*) and black pine (*Pinus niger*). These species are well-adapted for living in continental climate, as well in urban areas.

Particulate matter (PM) found in the air is a complex mixture of heavy metals, elements, black carbon, soil and other substances and is the most abundant air pollutant [18]. Plant leaves act like a bio-filter by accumulating PM, even nano-sized PM, on the surfaces of leaves and shoots. The dry deposition of particles on leaf surfaces is the essential mechanism of the positive effect that plants have on air quality [19,20]. The rain can wash-off the deposited particles from the leaf surfaces, which can then be immobilized in the soil or resuspended. Several factors, such as the concentration, size, and composition of PM, can influence the dry deposition. It is well known that the species differ in their ability to accumulate particles [21] and it is very important to choose the optimal plant to serve as a part of the green infrastructure in a specific urban area. Both the macro- and microstructure of a plant species determines its potential for the mitigation of air pollutants [22]. The type of vegetation and its characteristics, such as foliage and shoots density, plant height, and leaf characteristics, play a significant role in ability of plants to purify air. Higher foliar density usually means a higher leaf deposition. On the other hand, foliage that is too dense can reduce the air flux through the canopy and, consequently, particle deposition [23]. Evergreen plants can capture higher quantities of pollutants in comparison to deciduous plants. This effect is especially pronounced in winter when the concentration of pollutants in the air is higher [24]. Additionally, smaller leaves or leaves covered with fine hairs or waxes were associated with a higher particulate deposition [25]. When planning green infrastructure, one must consider the characteristics of the planting site. In open areas near roads, taller plants more effectively mitigate the impact of dust plumes from traffic, which in proximity to the road, can be around two meters [26]. In so-called "street canyons", taller trees can reduce the dispersion of air pollutants and confine air pollution to the pedestrian level [21].

Other than the removal of particles from air, trees and shrubs in urban areas can promote carbon uptake and sequestration. According to European Green City Index, Zagreb ranks 26th out of 30 studied and compared cities. Especially poor results Zagreb achieved in the CO_2 emissions part with an average of 6.68 tons of CO_2 per capita. Numerous tree species have been shown to be particularly successful in carbon sequestration, such as white poplar (*Populus alba)* and common *oak* (*Quercus robur)*. Other species such as stone pine (*Pinus pinea)*, horse chestnut (*Aesculus hippocastanum)* and European white poplar (*P. alba*) are effective for removing CO, O_3, NO_2 and SO_2 from the air, while *A. hippocastanum* very effectively removes PM_{10}. Authors found that *P. pinea, A. hippocastanum* and *P. alba* are the best species for the removal of total pollutants [27]. A couple more species are successful for removing air pollutants. Small-leaved lime (*Tilia cordata*) has a dense foliage that enhances the accumulation of PM, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) in open areas [28]. Leaves of the birch tree (*Betula pendula*) are rich in waxes that accumulate PM [25]. Field maple (*Acer campestre*) is one of the most tolerant trees of urban conditions [29].

Tree barriers impact air fluxes, and thus promote the deposition of particles. However, when vegetation is within 20 m of the road, the impact zone of the dust plume from the traffic is concentrated in the first two meters from the ground [26]. Additionally, needles of coniferous trees such as *P. pinea* and yew (*Taxus baccata)* produce a thicker wax layer, making them more effective for PM accumulation than broad-leaved species, including during the winter [27,30]. In urban areas, there is a limited space for planting, so in order to have an effective vegetation barrier, there must be a full coverage from the ground to the top of the canopy. Shrubs such as viburnum (*Viburnum lucidum*), red tip photinia (*Photinia x fraseri*), and Japanese spindle (*Euonymus japonicus*) are a good choice when designing a green barrier [18]. Both viburnum and photinia are vigorous evergreen shrubs or small trees with a dense, rounded crown. *Euonymus japonicus* is a rapid-growing evergreen shrub, so it can efficiently reduce PM in winter. It has a strong ability to adapt the environment, and it is pollution-, drought-, disease-, and heat-resistant. The *E. japonicus* leaves are smooth with a thick wax layer and concave stoma, which increases their ability to capture particulate matter from air [31]. Apart from the aforementioned trees and shrubs, numerous other species are also suitable for planting in the continental climate of the Zagreb urban area. A well-thought-out combination of deciduous and evergreen species can optimize year-round PM removal.

In last 20 years, many scientific studies have been conducted regarding calculating urban areas, green spaces, etc. The authors of [32] determined areas where changes in urban vegetation occurred based on satellite imagery and lidar data. The authors of [8] estimated economic well-being using high-resolution satellite imagery, while [33] mapped private gardens in urban areas using object-oriented techniques and very-high-resolution satellite imagery. The authors of [34] calculated the demarcation of prime farmland protection areas around metropolis areas based on high-resolution satellite imagery. Since mapping urban areas and vegetation is a popular topic, it is almost impossible to mention all relevant authors in this research field. Most of the authors considered mapping different species of vegetation on different imagery and with different methods [35–37].

This paper aims to show that, even in highly urbanized areas, such as Zagreb, the number of urban trees and shrubs can be significantly increased; consequently, negative air pollution effects for main traffic roads in city of Zagreb can be reduced. This paper is limited to a focus only on air pollution as a spatial transport problem. We do not address alternatives, such as pricing commuting to reduce number of cars. This paper presents novelty findings for using machine learning for the specific purpose of defining green urban areas to, determining possible locations for planting trees and, therefore, reducing pollutions in cities. Although, for some other parts of the world, the possibilities for green urban areas have been calculated, for this region and the city of Zagreb, this is first article on this topic. This article will have a huge impact on different understandings of possibilities in large cities with similar land cover.

2. Common Air Pollutants

Outdoor air pollutants are a wide group of chemical substances of both natural and anthropogenic origin. Nowadays, the emphasis is placed on study of anthropogenic emissions and their possible reduction through regulatory and voluntary actions. According to EPA, six pollutants are referred as "criteria pollutants" since acceptable levels for these substances are regulated by human-health and environment-based criteria. The criteria pollutants are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter of different size fractions ($PM_{2.5}$ and PM_{10}), and sulphur dioxide (SO_2).

Nitrogen dioxide is an orange–brown gas with a pungent, acrid odor. In higher concentrations, it causes lung damage, and in smaller doses, it causes cough, dyspnea, chest pain and hemoptysis [38]. The main sources of outdoor NO_2 are road traffic and energy production. Nitrogen dioxide is a primary pollutant, but it can also contribute to the formation of secondary pollutants, such as ozone, through chemical reactions.

Carbon monoxide (CO) is a colorless, odorless gas that forms during the incomplete combustion of any carbonaceous material. The main source of carbon monoxide in urban areas is vehicle exhaust smoke. In higher concentrations, it can be lethal since it decreases oxygen-carrying capacity, causing hypoxia. In smaller concentrations, it can cause a range of symptoms, such as headache, nausea and vomiting, weakness, and lethargy.

Particulate matter or particle pollution is a term for a mixture of solid particles, such as dust, dirt, soot, or smoke, and liquid droplets found in the air. It occurs in different sizes, and part of these particulates can be seen by naked eye, while others are so small that they can only be detected using an electron microscope. Two main categories of particle are studied today: inhalable particles with diameters that are $\leq$10 µm (PM_{10}) and ($PM_{2.5}$) very fine inhalable particles with diameters that are $\leq$2.5 µm. The smaller diameter of a particle can significantly increase its risk to human health. Once inhaled, these fine particles can penetrate deep into the lungs and even enter the bloodstream. The removal of lead from gasoline, improved engine designs, low-sulphur fuels, and especially diesel particulate filters contributed to the reduction in particulate pollutants from vehicles. Particles originating from vehicle brake pads and drums are currently almost equal to tailpipe emissions and are bound to surpass tail pipe emissions soon. Although little is known about the size and composition of wear particles, the abrasion of brake pads and drums is known to be a major source of ultra-fine metals [39,40].

3. Materials and methods

3.1. Study Area

Study area is in the city of Zagreb, the capital of Croatia. Zagreb lies under the mountain Medvednica and stretches along the left and right banks of the Sava River. Urban city center is populated with buildings, while outside the city center, there are recreational parks and green urban areas. Figure 1 presents the city of Zagreb as seen on RGB composition of WorldView-2 imagery. Based on CORINE land cover [41], this study area is separated into five classes in order to perform supervised machine learning using random forest classifiers. The five classes are as follows:

1. Inland waters—lakes, ponds and pools of natural origin containing fresh water and running water made entirely of rivers and streams. Man-made fresh water bodies are included [41].
2. Forests—areas occupied by forests and woodlands with a vegetation pattern composed of native or exotic coniferous and/or deciduous trees, which can be used for the production of timber or other forest products [41].
3. Green urban areas—includes area with vegetation within urban fabric; parks and cemeteries are included [41].
4. Arable land—includes land under a rotation system used for harvesting plants and fallow lands [41].
5. Urban fabric—areas occupied by dwellings and buildings used for administrative or public utilities [41].

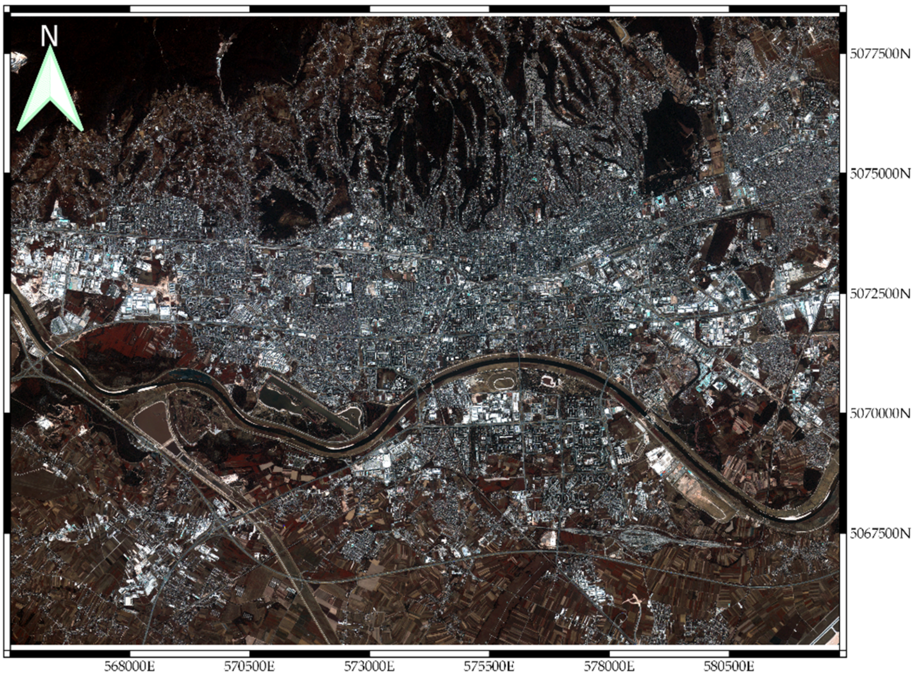

Figure 1. City of Zagreb: RGB composition of WorldView-2 imagery [38].

3.2. WorldView-2 Imagery

The WorldView-2 is Sun-synchronous sensor, which offers a high-resolution panchromatic band and eight multispectral bans [42]. Multispectral bands are four standard colors (red, green, blue and near-infrared 1) and four new bands (coastal, yellow, red edge and near-infrared 2) [42]. There are three available products for download: standard (2A)/ortho ready standard (OR2A), ortho ready stereo, and map scale ortho 1:12000 orthorectified. Spatial resolution of RGB channels is 1.24 m, while spectral range is from 400 nm (coastal blue) to 1040 nm (near-infrared). For this paper, red, green and blue bands are used with spectral resolutions of 450–510 nm for the blue band, 518–580 nm for green band and 630–690 nm for red band. Data for the city of Zagreb was downloaded from [43]. Recording date was 13 August 2013, and standard (2A) product was downloaded.

3.3. Random Forest Classifier

Machine learning is an artificial intelligence technique that teaches computers to think like humans by analyzing and learning from past experiences. It works by detecting data and identifying patterns and involves minimal human intervention. Deep learning is a type of machine learning and works like machine learning, but there are so many levels of these algorithms, and each offers a different interpretation of the data. Machine learning can take from few seconds to a few hours, while deep learning can take a few hours to few weeks. Due to faster time of execution, machine learning method was selected. Random forest is machine learning method that combines trees in such a way that each tree depends on a random vector value, which is independently sampled and evenly distributed for all trees in a forest [44]. The authors tested different machine learning methods for urban pattern recognition on very-high-resolution imagery, such as WorldView-2, and random forest was the best-performing classifier for very-high resolution imagery [45]. Kranjčić et al. (2019) [46] showed that random forest could be used on medium resolution imagery and produced very high results. They also defined parameters for the very-high-quality extraction of green urban areas [46]. Therefore, their parameters are used in this study for supervised classification. Several parameters can affect the results of classification, such as maximum tree depth, minimum sample count or maximum number of categories. Maximum tree depth represents the total depth of the tree; a low value can result in underfitting, while large value can result in overfitting. Minimum sample count presents necessary minimum samples number at a leaf node in order to be split. Common value is a small percentage of the total number of samples [46]. Maximum tree depth was set to 30, maximum sample count was set to 6, and maximum number of categories was set to 5. Maximum number of categories presents possible values of a categorical variable, which are clustered into K < max_categories in order to find a suboptimal split [46]. In other words, maximum number of categories will match how many classes we want on our scene. According to the literature [47] even small number of samples will result in high-accuracy classification. Figure 2 presents WorldView-2 imagery, training samples, control samples and busiest main roads in city of Zagreb. Roads presented in Figure 2 are manually vectorized based on WorldView-2 imagery and selected due to reports of long traffic jams on this roads [6]. Classification was performed in SAGA GIS on a computer with Intel® Core™ i7-8550u, 16GB RAM, 64bit on Windows 10 operating system. Classification accuracy was presented using confusion matrix [48]. Omission, commission, estimated kappa and overall kappa can be seen from confusion matrix. Confusion matrix presents the class types that are determined from the classified map and rows and the class types that are determined from the reference source in columns. Correctly classified data are shown on diagonals [48]. The kappa value measures the similarity between signature and control samples, and value higher than 0.80 denotes high classification accuracy [49]. A commission error occurs when polygons from different classes are located in reference data, while an omission error appears when the reference polygons are located in other classes [50]. In general, very high classification accuracy is achieved when overall kappa is larger than 0.80. Figure 3 presents methodology flowchart for this paper.

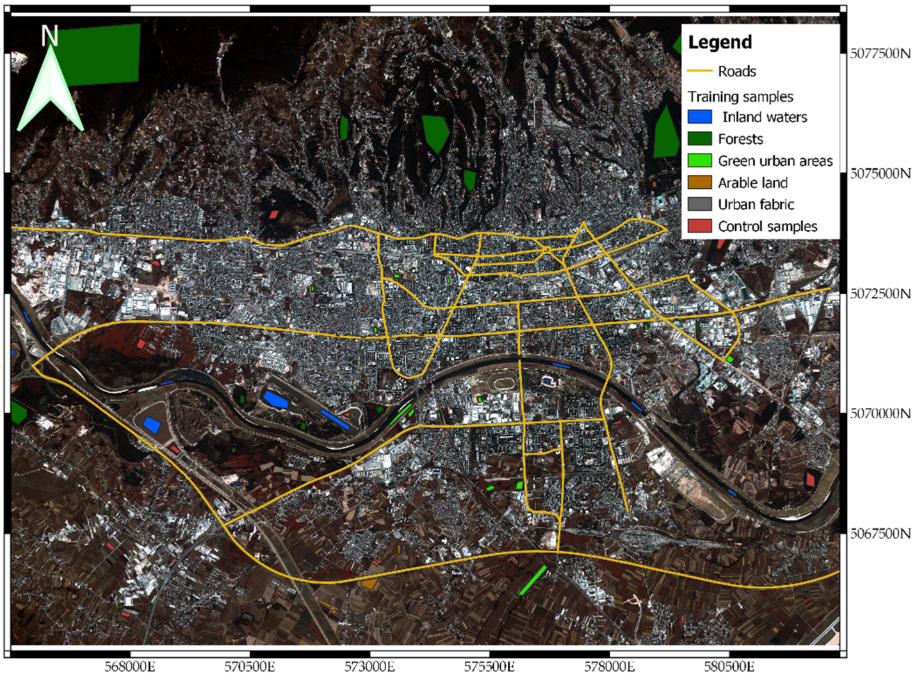

Figure 2. Roads, training and control samples [38].

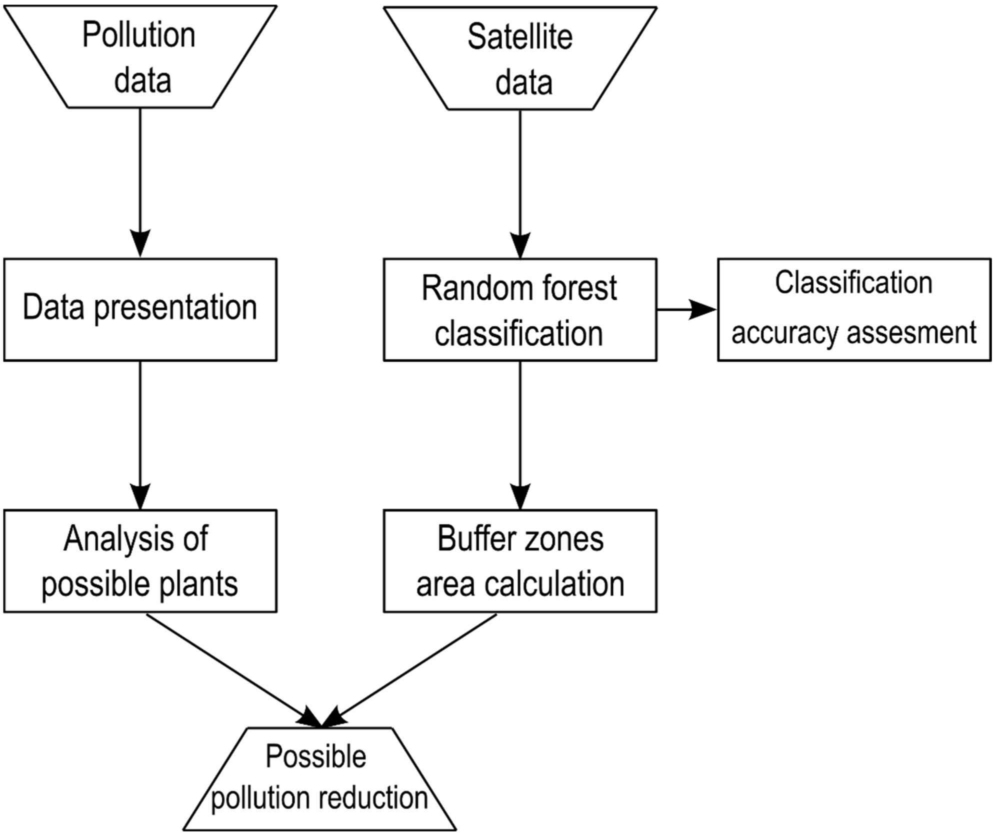

Figure 3. Methodology flowchart.

In three locations in Zagreb, air pollutants have been measured over the last 5 years. The three measuring stations (Zagreb-1, Zagreb-2, Zagreb-3) are part of the National Network for Continuous Air Quality Monitoring. The stations are equipped with devices for automatic analysis of monitored parameters and equipment for active collecting. They are located in an urban area and in the vicinity of busy streets. Table 1 presents the measuring equipment and techniques used in all 3 stations. Station Zagreb-1 is in the vicinity of the Miramarska and Vukovarska street, the crossroads in the center of Zagreb (coordinates 45,800339, 15,974072). The measuring station is 30 m away from the nearest building and 5 m from the edge of the road. During rush hour, these are very busy streets with high intensity of traffic. Station Zagreb-2 is located in a larger grass area in the vicinity of the Mandlova and Maksimirska street crossroads in the eastern part of Zagreb (coordinates 45,823717, 16,035825). Since Maksimirska street is an important traffic corridor connecting the east of the city with the city center, this is also a very busy street. Station Zagreb-3 is located at the intersection of Sarajevska street and Kauzlarić passage in southern part of Zagreb (coordinates 45,764947, 16,006469). This station is also located in the urban area, in proximity to the main street and approximately 20 m from the nearest residential building. The urban morphology around the three sites and the traffic rates are similar since all three are located in the urban Zagreb area and in proximity to large multi-lane streets that serve as main traffic corridors for daily commuters. Figure 4 presents different air pollutants in three different locations in Zagreb as follows: (a1), (b1) and (c1) present CO pollutants; (a2), (b2), and (c2) show NO_2 pollutants; (a3), (b3) and (c3) show NO_x parameters; and (a4), (b4), and (c4) present PM_{10} particles. Values presented in the graphs are daily validated values.

Table 1. Measuring equipment and techniques at stations.

Pollutant	Equipment	Measuring Method	Detection Limit	Sapling Frequency
CO	Horiba APMA 360 CO analyzer	Non-dispersive infrared spectroscopy (NDIR)	0.07 mg/m^3 of ambient air	hour
NOx	Horiba APNA 360 NOx analyzer	Chemiluminescence	8.23 µg/m^3/day	hour
NO2	Horiba APNA 360 NOx analyzer	Chemiluminescence	8.23 µg/m^3/day	hour
PM10	Thermo Andersen ESM FH 62 IR	Beta ray attenuation by a two—beam—compensation		

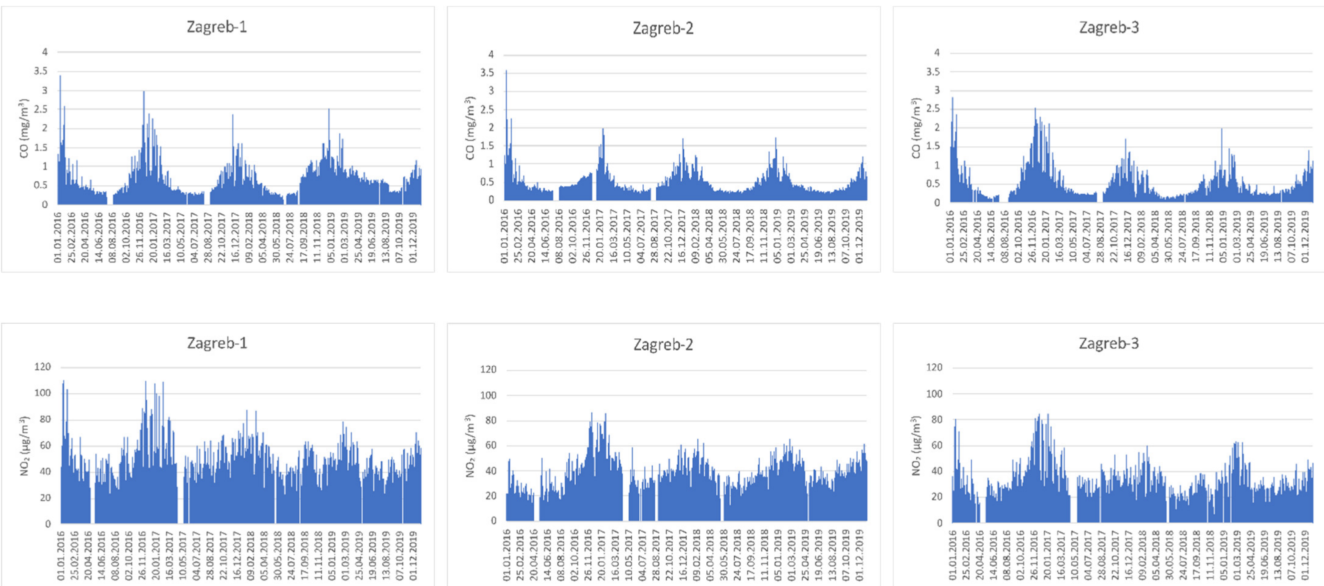

Figure 4. *Cont.*

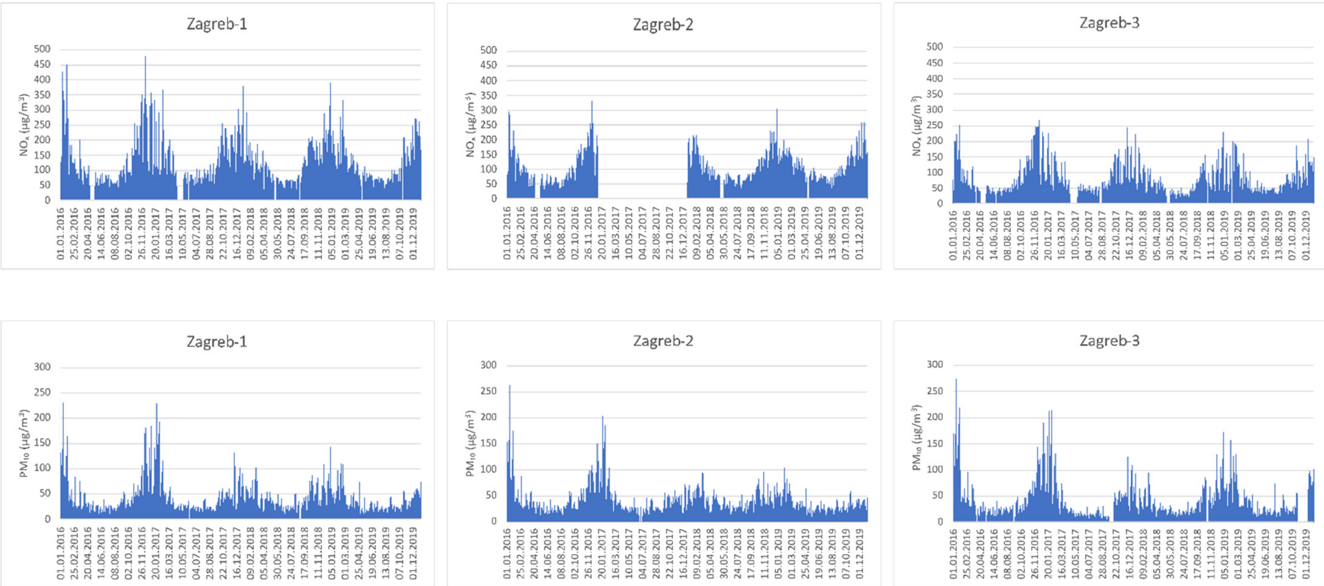

Figure 4. Air pollution in three different locations in Zagreb.

4. Results and Discussion

Clean air is an essential and constant need for human health, as well as for all forms of life on Earth. Numerous studies show that air pollution affects different aspects of health at even lower concentrations than previously known. On 26 May 2015 in Geneva, Switzerland, the 68th World Health Assembly adopted a landmark resolution, "Health and the environment: addressing the health impact of air pollution", identifying air pollution as a risk factor for nontransmissible diseases, such as asthma, ischaemic heart disease, stroke, chronic obstructive pulmonary disease, and cancer [51].

The WHO issued guidelines in 2021 as a means to offer quantitative health-based recommendations for air quality. These guidelines provide values for long- and short-term concentrations of a number of key air pollutants whose exceedance can pose a risk to public health (Table 2) [52].

Table 2. Recommended air quality guidelines (AQG) levels and interim targets.

Pollutant	Averaging Time	Interim Target				AQG Level
		1	2	3	4	
$PM_{2.5}$ μg/m^3	Annual	35	25	15	10	5
	24-h	75	50	37.5	25	15
PM_{10} μg/m^3	Annual	70	50	30	20	15
	24-h	150	100	75	50	45
O_3 μg/m^3	Peak season	100	70	n.a.	n.a	60
	8-h	160	120	n.a.	n.a	100
NO_2 μg/m^3	Annual	40	30	20	n.a	10
	24-h	120	50	n.a.	n.a	25
SO_2 μg/m^3	24-h	125	50	n.a.	n.a	40
CO mg/m^3	24-h	7	n.a.	n.a.	n.a	4

Interim target concentrations are proposed as steps for a gradual reduction in air pollution and are to be used in areas where air pollution is high.

By comparing the measured values with the values prescribed by the WHO, it is noticeable that the air quality in Zagreb is poor and can result in a number of health problems in the population. As can be seen from Figure 4, air quality changes seasonally.

During colder months, air quality is poorer than during warmer months. In 2017, the values of PM10 were higher than limit value (50 μg/m^3) for 78 days at the Zagreb-3 measuring station. In 2018, the values of PM10 were higher than the limit values for 46 and 63 days at the Zagreb-1 and Zagreb-3 measuring stations, respectively. During 2019, PM10 values were higher than 50 μg/m^3 for 53 days. Values for NO2 were exceeded during 2017 and 2019 at the measuring station Zagreb-1 [53–55]. Figure 5 presents classification results, and Table 3 presents classification accuracy. Classification is just a determination of the land use of this study area.

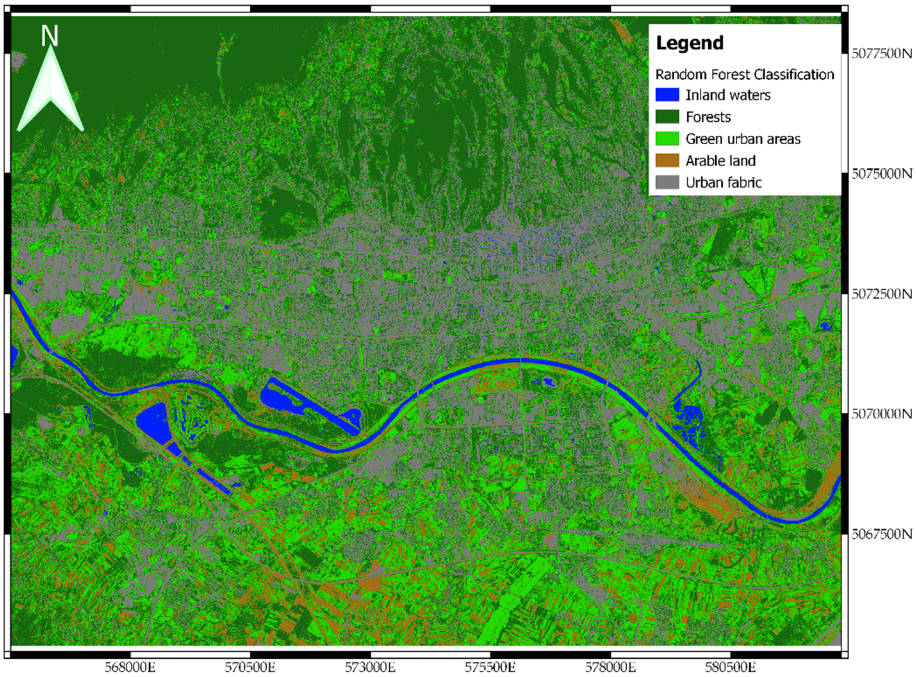

Figure 5. Random forest classification result [38].

Table 3. Random forest accuracy assessment.

Class	Commission	Omission	Estimated Kappa
Inland waters	2.71	26.11	0.97
Forests	0.03	0.29	0.97
Green urban areas	3.15	3.98	0.97
Arable land	14.99	3.10	0.79
Urban fabric	58.15	41.00	0.59
Overall κappa		0.88	

As seen from Figure 5 and Table 3, classification achieved very high accuracy. From Figure 5, it can be seen that the city of Zagreb is relatively populated with forests and green urban areas. However, the main issue is the non-existence of plants that could absorb pollutants around roads. Figure 6 highlights the main possibilities for planting plants to reduce air pollutants and from (a) to (d) are presented selected areas for analysis.

After classification, results presented very high classification accuracy, two buffer zones around roads were created: one with a 10 m distance, and another with 15 m. Buffer zones were arbitrarily created. A classification raster was clipped with both buffers. Areas around the roads where land cover was arable land were calculated. Figure 7 presents the highlighted results of clipped classification results and areas from (a) to (d) present analyzed areas according to Figure 6. Table 4 presents areas in square meters where plants could be planted. Planting was planned as a random distribution along the roads according with the estimated tree coverage.

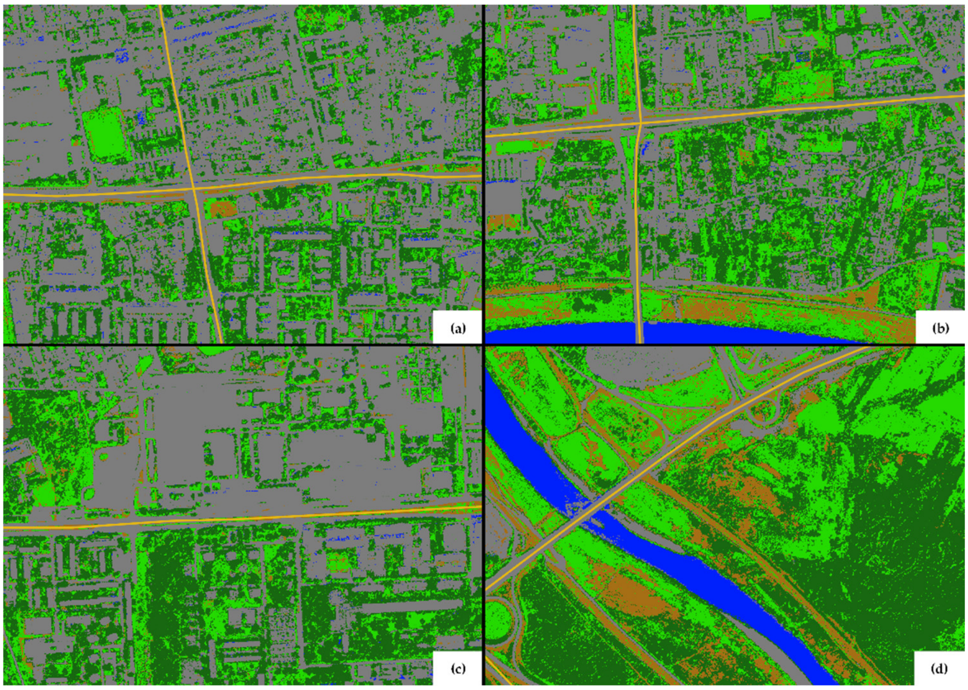

Figure 6. Possibilities for plants that reduce air pollutants [38].

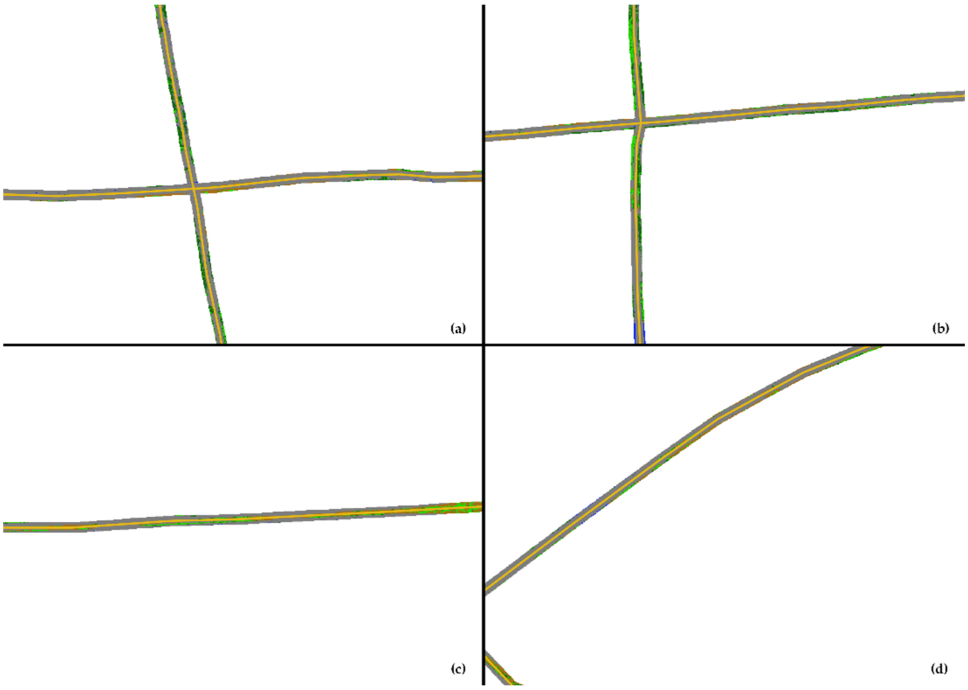

Figure 7. Highlighted results of clipped classification with 15 m buffer.

Table 4. Potential planting areas (in square meters).

Land Cover	10 m Buffer	15 m Buffer
Green urban areas	138,826	255,309
Arable land	89,101	154,972
Total	227,927	410,281

Chosen zones can be classified as roads, and types of green infrastructure are accordingly proposed. When planning and measuring a green barrier, one must take several factors into account in order to achieve optimal conditions for air pollution mitigation. The height of vegetation barriers must be higher than the smog plume from the vehicular emission, and the proposed value for this parameter is 4–5 m. Suggested shrub species can be pruned to achieve a desirable height and to cover the undergrowth area beneath higher trees. The thickness of the vegetation barrier depends on the foliar density and can vary from minimum 5 m to 10 m and more depending on the available planting area. Thickness is one of the most important parameters that influences the effectiveness of the barriers. Too thick a barrier acts as a wall, and the majority of the pollutant fluxes can go over the barrier instead of through it. On the other hand, if the barrier lacks density or has gaps, pollutant fluxes can preferentially pass through the vegetation. The length of the barrier should be at least 50 m longer than the concerned area in order to prevent lateral passing of the pollutant fluxes [23,56]. Mori et al. (2018) [18] compared the efficiency of two species and two planting densities, 1 plant per m^2 and 0.5 plants per m^2 barrier, observing that transects with a higher total leaf area, had the highest deposition of particle matter per unit of leaf area regardless of the species and planting density. For the purpose of this paper, a moderate estimation of 2 m^2 of area for one shrub and 10 m^2 for a larger trees was considered. From Table 5, it is seen how many plants could be planted on available area. The proposed species are part of the standard layout of Zagreb's parks and streets, although we suggest that the number of species should be expanded in order to increase resistance to diseases and pests. Almost half of the trees in European cities belong to between 3 and 5 genera (*Acer*, *Aesculus*, *Platanus* and *Tilia*) [57]. Many non-native species would fit perfectly into the climatic conditions prevailing in Zagreb.

Table 5. Possible number of plants.

Plant Name	10 m Buffer	15 m Buffer
Tilia cordata *Aesculus hippocastanum* *Pinus* sp. *Taxus baccata* *Populus alba* *Quercus robur* *Betula pendula*	22,792	41,028
Viburnum lucidum *Photinia x fraseri* *Euonymus japonicus*	113,963	205,140
Total	227,927	410,281
Increase in vegetation areas	3.0%	5.6%

The mitigation effects of these areas, if planted, would have to be calculated according to the methodology proposed by Jim et al. (2008) [58], where the pollutant flux (F) is calculated as the product of the deposition velocity (V_d) and the concentration of air pollutant (C). Total flux into urban trees of air pollutants i (F_t) can be assessed by multiplying the pollutant flux by the tree cover (A) in a certain time period (T). The level of air pollutants removed by urban trees (F) could be quantified as a sum of all of the obtained individual pollutant fluxes. For the purpose of calculation, it was assumed that the total available area suitable for planting was actually planted and the trees and shrubs had reached their physiological maturity (Table 6). Only values from the station Zagreb were used since it is the closest to the area of interest.

Table 6. Quantifying air pollutant removal in Mg.

Pollutant	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total	Removal Rate (kg/ha/y)
PM10	0.28	0.37	0.18	0.20	0.10	0.15	0.12	0.13	0.14	0.18	0.19	0.28	2.31	51.30
SO2	0.04	0.06	0.06	0.07	0.05	0.05	0.06	0.04	0.02	0.02	0.03	0.03	0.53	12.86
NO2	0.18	0.22	0.19	0.17	0.14	0.15	0.14	0.13	0.15	0.16	0.17	0.19	1.98	48.27

The highest impact of urban trees and shrubs on ozone, sulfur dioxide, and nitrogen dioxide concentrations is throughout the day during the in-leaf season (spring to autumn for deciduous plants) when trees are transpiring water. Particulate matter removal happens during both the day and night and over the year as particles are captured by leaf and bark surfaces. Evergreen trees and shrubs are especially useful during wintertime when the peak concentrations of air pollutants are observed (Figure 4). Carbon monoxide removal also happens both day and night during the in-leaf season [59].

Few studies have attempted to quantify the effect that green infrastructure has on mitigating air pollution. Yang et al. (2005) [60] showed that trees in the Beijing (China) city center removed 772 tons of PM_{10} during one year. Similar research conducted in Colorado, USA, showed that urban trees, which cover 11% of city area, removed approximately 234 tons of PM_{10} [61]. Nowak et al. (2005) [59] estimated that all the urban tree shrubs throughout the USA remove roughly 305 kilotons of ozone, 97 kilotons of NO_2, 70 kilotons of SO_2, 22 kilotons of CO, and 215 kilotons of PM_{10} every year. McDonald et al. (2007) [62] found that planting trees on 25% of the available urban areas in UK cities was able to reduce PM_{10} concentration by 2–10%. Listed amounts of removed pollutants have a direct positive effect on human health. Taking all of this into account, urban plants are possibly the best purification option for open air.

Wang et al. (2019) [63] found that silver birch (B. pendula) with a surface area of 125 m^2/tree and with a canopy diameter of 8 m, when planted next to a road in a row (8 trees/100 m), could reduce up to 50% of the traffic derived PM10. Additionally, in a street canyon, planting birch trees can significantly enhance indoor air quality by reducing PM1.0, PM2.5 and PM10 (60–80%).

Detailed and accurate estimates of the impact of green infrastructure on pollutant reduction are complicated, and values from different literature sources are sometimes difficult to compare due to different methodologies. The use of LAI (leaf area index) and LAD (leaf area density) values help in comparing the performance of individual plant species. Both values are density parameters, which describe the available vegetation area for deposition [64]. Generally speaking, downwind particle number concentration is reduced with an increase in LAD [65]. Since natural species have different LAD values depending on the morphological characteristics, performed studies [66] suggest that the optimal LAD values should be between 3 and 4 m^2/m^3.

It is important to emphasize that the optimal density required for the effective removal of pollutants can be achieved not only by selecting the appropriate plant species, but also by the further care of planted plants in the form of pruning and thinning dense structures or additional planting if the density is too low [67].

When considering urban greenery as a possible solution for air pollution, one must also take into account the possible detrimental effects of poorly designed green infrastructure can have due to aerodynamic effects, especially in close roads (e.g., street canyons). For this reason, an in-depth interdisciplinary approach is needed when dealing with air quality, urban greenery and the best possible outcome for all.

5. Conclusions

This study presents air pollutants on main traffic roads in the city of Zagreb. Green urban areas are important for reducing air pollutants as well for the well-being of the population. Based on satellite data and machine learning, the main possible planting areas were defined for the city of Zagreb. From the results, it can be seen that if we take conservative approach, around 113,963 shrubs and 22,792 trees can be planted in a 10 m buffer zone. In a 15 m buffer zone, 205,140 shrubs and 41,028 trees can be planted. Based on cautious approach, the planting of trees and shrubs could increase the vegetation population from 3 to 5% in city of Zagreb, which would have a positive effect not only on the reduction in air pollutants, but on public health as well. This paper presents novelty findings in machine learning for the specific purpose of defining green urban areas to determine possible locations for planting trees, and thus reducing pollutions in cities. Up until now, different machine learning algorithms have been applied to map green urban infrastructure. This paper presents the multidisciplinary application of remote sensing techniques to improve the mapping of green urban areas and provide possible areas to establish green infrastructure that could reduce pollution. Although, for some other parts of the world, the possibilities for green urban areas are calculated, for the region and the city of Zagreb, this is first article on this topic. This article will have a huge impact and different understanding of possibilities in large cities with similar land cover. Future work will focus on creating planting phases to successfully reduce air pollutants in large cities. The limitations of this study are due to the restrictions of available traffic data and a focus only on the environmental part of the reduction in pollution, without taking economic values into consideration. Future research must include an evaluation of different machine learning and deep learning techniques using much cheaper methods, such as simply planting trees along main roads. Additionally, future research must present recommendations to stakeholders based on stakeholders' analyses. General recommendations to the stakeholder would be that proper planning and the involvement of the professionals in solving problems is necessary to enhance use of urban greenery to improve air quality, lower the temperature, and generally improve the quality of life in the city.

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