Evaluating the sensitivity of the i-Tree Eco pollution model to different pollution data inputs: a case study from Warsaw, Poland

Zbigniew Szkop
University of Warsaw
Faculty of Economic Sciences
zszkop@wne.uw.edu.pl

Długa Street 44/50
00-241 Warsaw
Poland

Acknowledgments:

This research was funded by a grant from the National Science Centre (number 2016/23/N/HS4/03674)

The author would like to express his appreciation to the team working at the Davey Institute/USDA Forest Service, and especially to Jason Henning, who helped him during this study.

Abstract

Urban trees provide a range of ecosystem services, including air purification. This specific ecosystem service can be quantified using i-Tree Eco software, but the software has some limitations. One limitation is that the pollution model used in the software cannot take into account spatial differences in pollutant concentrations, which occur in every city due to the diversity of polluters. This study aimed to investigate to what extent this limitation of the i-Tree Eco pollution model can influence the results obtained. The study was conducted in such a way that the i-Tree Eco project was broken down into four sub-projects, in which data on the concentration of selected pollutants from different air quality monitoring stations were analyzed using the coefficient of variation (CV). Three stations were designated as "urban background" type stations and one was a "traffic" type station. The study revealed relatively low variation ($0.05 < CV < 0.23$) in estimated quantities obtained based on concentrations of pollutants retrieved from different air quality monitoring stations of the same type ("urban background" type stations) and relatively high variation ($0.24 < CV < 0.57$) in estimated quantities obtained on data retrieved from different types of stations (“urban background” versus “traffic”).When data on air pollutant concentrations used in the model is from the “traffic” station type, trees provide air purification ecosystem services with an annual value almost twice as high (EUR 310 000) as when the data used is from “urban background” stations type (EUR 165 000). The results highlight the importance of ensuring that appropriate air pollution data for running a particular type of i-Tree Eco project is used.

Keywords: Air quality, ecosystem services, human well-being, software limitation, urban trees

1. Introduction

Urbanization is increasing on a global scale, creating both opportunities and challenges for improving people’s quality of life and managing the transition towards sustainability. The world urban population in 2050 will be approximately 63% of the global population (Estevez et al., 2016). In the context of a rapidly urbanizing world, understanding complexity and managing human-environment interactions within urban areas is vital if we are to balance the interdependent social and ecological goals of sustainability (Bettencourt and West, 2010). A comprehensive planning approach has the potential to harmonize human-environment interactions and mitigate the harmful impacts of urbanization (Andersson, 2006). Such an approach requires planners to understand and value nature's multiple contributions to the quality of urban life and to capture these values in suitable governance mechanisms (Hubacek and Kronenberg, 2013).

One of the most important environmental challenges in urban areas is air quality. Air pollution caused by human activity has been a problem since the beginning of the industrial revolution. With increasing population, industrialization and industrial activities, largely as a result of increasing energy generation and the use of transport based on fossil fuels, large quantities of pollutants have been produced. The main generators of air pollution and the causes of the presence of these gases in the urban atmosphere are transport, industry, electrical power generation, domestic heating and the incineration of solid urban waste (Pauleit and Duhme, 2000).

In the last few years, various studies have been carried out to confirm that air pollutants have damaging effects on human health (Al-Hemoud et al., 2018; De Marco et al., 2019; Zhou et al., 2015). According to the Health and Environment Alliance, in Europe alone it is estimated that 518 700 deaths a year are due to pollution (EEA, 2018). There are many studies (Eisenman et al., 2019; Jones and Goodkind, 2019; Nowak, 2014; Nowak et al., 2019) showing that urban vegetation can have a positive impact on air quality and therefore the health of city dwellers. It is important to conduct studies on the ability of urban trees to remove air pollution and the value of that ecosystem service, as quantification can not only raise environmental awareness but also help policymakers to better manage urban greenery to achieve the desired environmental improvements (Raum et al., 2019).

In order to generate knowledge that is relevant for decision-makers, the study needs to be carefully contextualized in relation to the specific locations in which air purification ecosystem services occur and are utilized. Carefully contextualized urban ecosystem services study is particularly important when using benefit transfer (BT) approach-based software such as i-Tree Eco (Plummer, 2009). If the assessments of urban ecosystem services do not capture the contextual diversity of urban ecosystem service provision, then there will be serious knowledge gaps regarding the relationships between urban ecosystem services and human wellbeing. To better understand possible knowledge gaps between evidence and practice, this study investigates to what extent results can be influenced by the limitations of the i-Tree Eco pollution model in regard to capturing spatial diversity of air pollution occurring in the city area.

2. State of the art regarding i-Tree Eco studies

It is a fact that trees can help lower the local concentration of pollution in the air. Yet the importance of vegetation for the improvement of air quality depends on many factors. These include, among others, structure and species composition of urban trees, air pollution level, weather conditions, and characteristics of the population affected by air pollution (Hiemstra et al., 2008). Depending on these factors, the net benefits for city dwellers in terms of improving air quality as a result of an investment in planting certain trees may vary.

The limited nature of physical, financial, human and natural resources means that policymakers must make careful decisions regarding strategies for tree planting by comparing the benefits and tradeoffs of different planting scenarios (Hotte et al., 2016). In this context, it should be noted that the results obtained from the quantification of the air purification ecosystem services should be as accurate as possible. Therefore, it would be preferable to carry out empirical studies in each case at the location concerned ("*in situ*" studies). Unfortunately, it is difficult to carry out an *in situ* study on the ability of certain trees to absorb dust and gas pollutants from a given area of the city. Although it is theoretically possible, it would be very costly and would expose the inhabitants of a given city to great inconvenience. Instead, this type of research is done in laboratories, recording how many toxic substances can be absorbed by a tree with a given leaf surface area, depending on the concentration of these substances in the air and the climatic and meteorological conditions (Żylicz, 2017). Such studies have been carried out by Baldocchi et al. (1987), Beckett et al. (2000), Lovett (1994), Nowak et al. (1998).

Although the leaf area (LA) of urban trees could be calculated in an *in situ* study, for instance utilizing LIDAR technology, due to the cost of such a study this is usually carried out with the BT approach. Using this approach, estimates of the LA of trees growing in a certain location are based on original *in situ* studies carried out elsewhere. An example of an original *in situ* study during which the LA of selected trees of different species and other parameters were accurately measured is Nowak (1996). Later, based on the collected data, regression equations were developed for the most common urban tree species, where the dependent variable was the LA and the independent variables were other parameters of the trees.

Software that uses the results of such meticulous studies to facilitate the estimation of LA of trees based on their basic parameters, followed by an estimation of the absorption of several typical contaminants by trees based on the size of their LA, the concentration of contaminants, and the prevailing climatic and meteorological conditions is called i-Tree Eco (Hirabayashi et al., 2015).

Studies using i-Tree Eco software have gained popularity in recent years not only in the United States, but in many other countries: Canada (Foster and Duinker, 2017; Lefrançois, 2015), Colombia (Bautista and Peña-Guzmán, 2019), Mexico (De la Concha, 2017), Puerto Rico (Meléndez-Ackerman et al., 2018), Dominican Republic (Bauer et al., 2016), Germany (Scholz et al., 2018), Spain (Baró et al., 2014; Chaparro and Terradas, 2009), France (Nowak, 2018), Hungary (Kiss et al., 2015), The Netherlands (Medrano, 2019), Poland (Siedlarczyk et al., 2019; Szkop, 2016), Portugal (Graça et al., 2017), the United Kingdom (Doick et al., 2017; Hutchings et al., 2012; Raum et al., 2019; Rogers et al., 2015), Australia (Blair et al., 2017; Gardner et al., 2017), and China (Wu et al., 2019). Some of these studies are purely application-oriented while others are purely for research.

In this context, however, it is worth noting certain limitations of the i-Tree Eco software which should be borne in mind when interpreting results. One of them is that for the i-Tree Eco projects, the algorithms used by the i-Tree Eco pollution model do not take into account the spatial diversity of air pollution that may occur in an area due to the diversity of polluters. Although trees can take up large quantities of pollutants, they are only able to do so when the pollution is in their immediate environment. Thus trees in one area will not be able to affect air contamination in other areas, although they may have a significant capacity to do so. This highlights the importance of using air pollution data representative for that tree’s immediate environment when estimating the amount of pollution being absorbed by a tree. This is of particular concern when the project is run for a large and diverse area such as an entire city.

When conducting an i-Tree Eco project, only data from a single air quality monitoring station can be used. This station should be the most representative of the entire study area. The procedure of employing data from only one air quality monitoring station can undoubtedly cause an error in estimates of the model. The aim of this study was to evaluate the sensitivity of the i-Tree Eco pollution model to different pollution data inputs in order to find out to what extent the above-mentioned limitation of the model can affect the results. Specific questions addressed are:

1) By how much are the results influenced by the choice of an appropriate (the most representative for the whole city area) "urban background" station.
2) By how much are the results influenced by the choice of station type ("urban background" vs. "traffic").

The hypothesis underlying this study was that the limitation of the i-Tree Eco pollution model used in i-Tree Eco software with respect to the lack of ability to take into account spatial differences in air pollution occurring in the city area may substantially affect the estimated annual quantities of air pollutants absorbed by trees, as determined by the software, and thus lead to an inaccurate estimate of the economic value of that ecosystem service.

According to the author's knowledge, this is the first study investigating the impact of the inability of the i-Tree Eco pollution model to take into account the spatial differences in pollutant concentrations in the city area on the results obtained. There are many studies on spatial differences in concentrations of air pollutants in cities (e.g. Aristodemou et al., 2018; Bijad et al., 2016; Douglas et al., 2017; Zhong et al., 2011), but they are general and do not refer to the air purification ecosystem service of urban trees. The impact of the location of urban tree planting sites on their ability to purify the air has been discussed by Morani et al. (2011), but in this study, the authors did not refer to the limitations of i-Tree Eco software. The most methodologically similar study to the one presented here was done by Rogers et al. (2015), but it had a very different purpose, which was to estimate more precisely the value of analyzed ecosystem services.

3. Methods and materials

In order to evaluate the sensitivity of the i-Tree Eco (v6) pollution model to different pollution data inputs, the i-Tree Eco project for the street trees in Warsaw, Poland was carried out and the results analyzed using the coefficient of variation (CV). The CV represents the ratio of the standard deviation to the mean, and is used for comparing the degree of variation from one data series to another, even when the means show great differences between one another (Brown, 1998).

The tree parameters necessary for i-Tree Eco modeling, namely, species, diameter at breast height, total tree height, crown size, and crown health, were obtained from an inventory of 149 476 street trees conducted in Warsaw between the years 2010-2015 (ZZM, 2017). Figure 1 shows the location of the trees that have been inventoried in Warsaw.

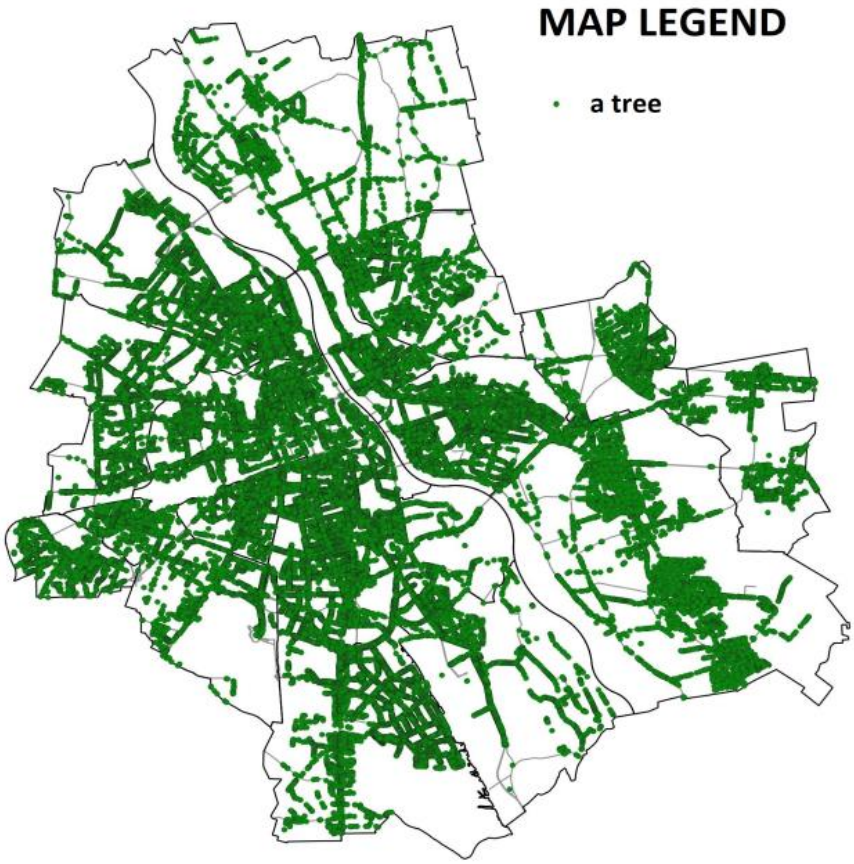


Figure 1. Location of street trees in Warsaw

The inventory shows that *Tilia cordata* Mill. (small-leaved lime) is the most common tree species in the streets of Warsaw. Tilia cordata and the second most common species, *Acer platanoides* L. (common maple), account for almost a quarter of all street trees growing in Warsaw (24%). Other popular tree species are *Betula pendula* Roth (papillary birch), *Acer negundo* L. (ash-leaved maple), *Fraxinus excelsior* L. (ash-high), *Acer saccharinum* L. (silver clone), *Quercus robur* L. (pedunculate oak) and *Robinia pseudoacacia* L. (black locust). The species composition of trees in the streets of Warsaw is shown in Figure 2 below.

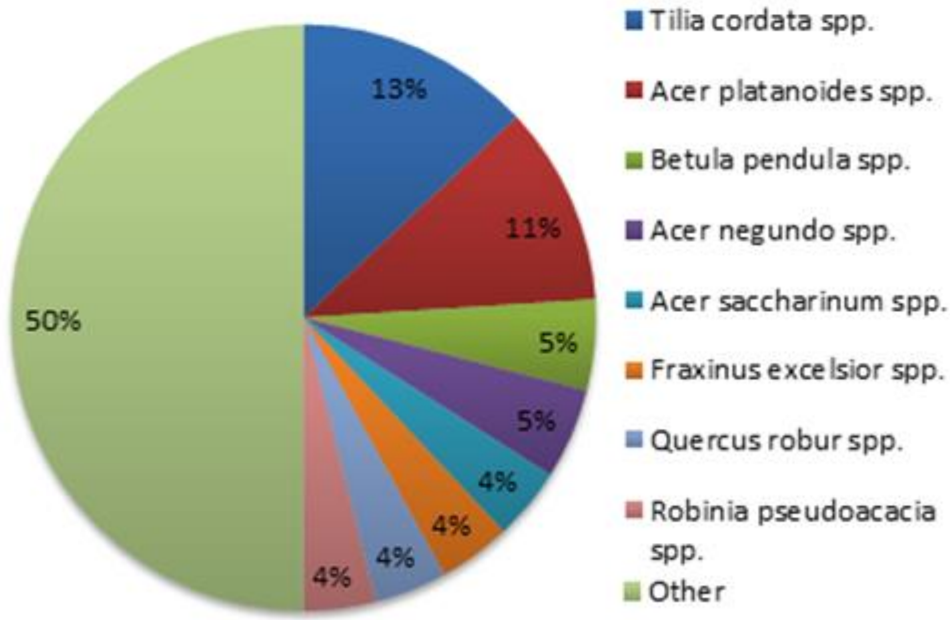


Figure 2. Species composition of the street tree population of Warsaw

In Warsaw, the concentrations of the pollutants NO_2, SO_2, and $PM_{2.5}$ were measured at three stations of the "urban background" type (WaT, WaKr, WaU), located in urban background areas of the city (e.g. city parks). In addition, concentrations of NO_2 and $PM_{2.5}$ (traffic-related air pollutants) were measured at one "traffic" type station (WaK), located in the traffic area of the city directly at a roadway with high traffic intensity. The locations of these stations are presented in Figure 3.

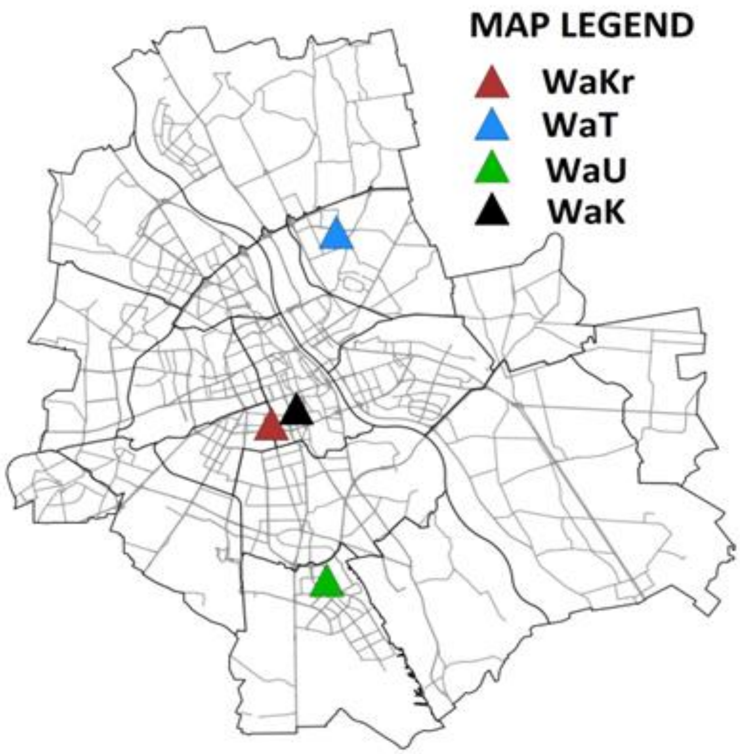
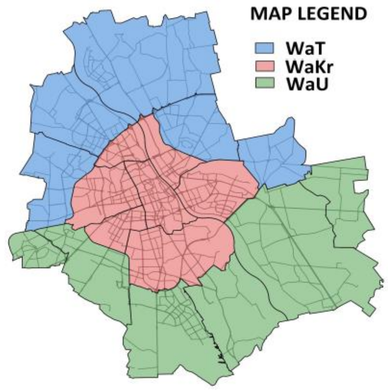


Figure 3: Location of air quality monitoring stations in Warsaw

The data on pollutant concentrations necessary for quantifying the air purification ecosystem service provided by Warsaw's street trees were derived from these four air quality monitoring stations. This was possible due to breaking the i-Tree Eco project into four sub-projects where different pollution concentration data can be used for different sub-projects. This non-standard procedure was possible due to close cooperation with the designers of the software (The Davey Institute/USDA Forest Service). The software itself does not provide the option to perform such an action. Breaking down the project into four sub-projects was conducted according to the procedure shown in Table 1.

Table 1: Methodology of the study

Sub-project	Aim	Included trees	Station	The spatial scope
1	Determining the lower limit of pollutants absorbed by all street trees in Warsaw	Street trees growing in the northern districts of the city	WaT (Urban background)	
2		Street trees growing in the central districts of the city	WaKr (Urban background)	
3		Street trees growing in the southern districts of the city	WaU (Urban background)	
4	Determining the upper limit of pollutants absorbed by all street trees in Warsaw	All the street trees growing in Warsaw	WaK (Traffic)	

The lower limit of pollutants absorbed by street trees in Warsaw was calculated using data on the concentration of these pollutants corresponding to the following criteria:

- For trees growing in the districts of Bemowo, Bielany, Białołęka, Targówek and Rembertów (northern districts), the data on the concentration of pollution from the Warszawa-Tagówek (WaT) background station was used.
- For trees growing in the districts of Mokotów, Ochota, Wola, Śródmieście, Żoliborz, Praga-Południe, Praga-Północ (central districts), the data on the concentration of pollution from the Warszawa-Krucza (WaKr) background station was used.
- For trees growing in the districts of Ursus, Włochy, Ursynów, Wilanów, Wawer, Wesoła (southern districts), the data on the concentration of pollution from the Warszawa-Ursunów (WaU) background station was used.

It has been assumed that the concentration of these pollutants along some low traffic roads may be similar to the concentration of these pollutants occurring in urban background areas of the city (e.g. city parks), thus they are regarded as being representative of areas characteristic for "urban background” type stations. The upper limit of pollutants absorbed by street trees in Warsaw was calculated using data on the concentration of these pollutants recorded from the only available "traffic" type station, Warszawa-Komunikacyjna (WaK), regardless of the trees’ exact location in the city.

The amount of pollutants absorbed by street trees in Warsaw was estimated with the use of i-Tree Eco software, retrieving climatic and meteorological data from the Meteorological Station Meteo Warszawa-Okęcie. Data on air pollutant concentrations as well as climatic and meteorological data are from observations made in 2011. This is because it was one of the last years when the WaKr air quality monitoring station was in operation.

After obtaining the estimates in physical values (kg/year), the air purification ecosystem service was valuated (expressed in monetary terms i.e. EUR/year). The valuation of the benefits of improving air quality through the absorption of SO_2, NO_2, and $PM_{2.5}$ have been calculated on the basis of the external costs of these pollutants estimated in various European research projects and summarized in the ExterneE project (ExternE, 2005). The ExterneE methodology determines the external costs using the 'impact pathway' approach. In other words, by analyzing a series of events linking each of the activities concerned (e.g. the emission of an additional tonne of SO_2) and comparing this to its 'effects' (influence on human health, vegetation, material goods, etc.), the monetary value is determined.

The value of external costs depends, among others, on the size of the population which is exposed to the concentration of a given pollutant and the cost of treating air pollution-related diseases in a given country. Moreover, that cost always should be considered in relation to the underlying year of assessment. In the ExternE project, the values of external cost were calculated for two possible scenarios, these being impacts in present or future years. For the present years, 2010 was chosen as a reference year. For future years, the reference year was 2020. In the latter case, an escalation factor was used to consider the change in the monetary valuation of damages due to better welfare in general (ExternE, 2005).

Taking into account location-specific conditions for urbanized areas in Poland, the benefits of removing the three selected pollutants in terms of prevented damages and corresponding cost savings were estimated at: EUR 15.13 per kilogram of absorbed NO_2, EUR 9.98 per kilogram of SO_2 and EUR 46.98 per kilogram of $PM_{2.5}$ absorbed (reference year 2020).

4. Results

4.1 Quantities of absorbed pollutants

Modeling with i-Tree Eco software conducted in this study has shown that in total, street trees in Warsaw remove 5 576-12 513 kg NO_2, 1 455 kg SO_2 and 1 398-2 268 kg $PM_{2.5}$ annually from the air. The ranges represent the lower and the upper estimates based on the source of the air pollution data inputs (appropriate background station type versus traffic station type). As the concentration of SO_2 in the air (non-traffic-related air pollutant) was not measured at the "traffic" type station (WaK) at all, there is only one estimate for that air pollutant. On average, one street tree in Warsaw absorbs 0.06-0.11 kg of the above-mentioned air pollutants. These results are presented in Table 2.

Table 2: Quantities of pollutants absorbed by street trees in Warsaw

	NO_2	SO_2	$PM_{2,5}$
Total amount of pollutants absorbed by all street trees (kg/year)	5 576–12 513	1 455	1398–2 268
Average amount of pollutants absorbed by a single street tree (g/year)	37-84	10	9-15

The ability of trees to absorb pollutants depends to a large extent on the size of their leaf area (LA) and the concentration of these pollutants in the air. The study carried out allows one to compare the results obtained by the i-Tree Eco model, based on data retrieved from different air quality monitoring stations, while all the other factors, including the size of the leaf area, remain constant. The comparison was conducted for the most common tree species in Warsaw, T. cordata (small-leaved lime), with a leaf area of 200 $m^{2.}$ The results are presented in Table 3..

Table 3: The amount of pollution absorbed by *Tilia cordata* trees with a leaf surface of 200 m^2 at different air quality monitoring stations

Station (type)	NO_2	$PM_{2.5}$	SO_2
	(g/year)	(g/year)	(g/year)
WaT (urban background)	**41.67**	**11.17**	**10.24**
WaU (urban background)	**26.56**	**10.37**	**11.70**
WaKr (urban background)	**32.84**	**-**	**11.72**
Coefficient of variation for WaT, WaU, and WaKr	*0.23*	*0.05*	*0.08*
WaK (traffic)	**97.61**	**18.10**	**-**
Coefficient of variation for WaK and WaT	*0.40*	*0.24*	-
Coefficient of variation for WaK and WaU	*0.45*	*0.27*	-
Coefficient of variation for WaK and WaKr	*0.57*	-	-

The results indicate that the estimates are strongly influenced by the type of station from which the air pollution data was used for i-Tree Eco modeling.

The coefficient of variation (CV) shows relatively low variability ($0.05 < CV < 0.23$) of the results obtained from stations of the same type (“urban background” type stations), where the highest coefficient of variation was recorded for NO_2 (0.23), followed by SO_2 (0.08) and $PM_{2.5}$ (0.05). This indicates that it is of significant importance to run the i-Tree Eco project for trees growing in the urban background areas of the city using NO_2 concentration data which are the most representative for the whole project area. When this is ensured, i-Tree Eco modeling based on data on concentrations of air pollutants retrieved from a single monitoring station may not substantially affect the estimates for these trees.

The coefficient of variation shows relatively high variability ($0.24 < CV < 0.57$) of results obtained from different station types, where the coefficient of variation recorded for NO_2 ranged from 0.40 to 0.57 and $PM_{2.5}$ was between 0.24 and 0.27. The results show that the values obtained by employing the pollution concentration data derived from different types of monitoring stations may cause substantial differences in the values calculated by the i-Tree Eco pollution model. In terms of absolute numbers of pollutants being absorbed, these results show that a specific *T. cordata* tree growing in a traffic area (street with high traffic volume) in Warsaw can potentially absorb approximately 70% more $PM_{2.5}$ and almost 400% more NO_2 annually than a similar tree growing in an urban background area of the city (e.g. in city parks or along local roads with low traffic volumes). The i-Tree Eco pollution model cannot take into account these differences when calculating values based on data from a single monitoring station. Therefore running the i-Tree Eco project for trees growing on both background and traffic areas of the city while employing data from only one air quality monitoring station will substantially affect the estimates for some of the trees.

4.2 Economic value of air purification ecosystem services

Economic valuation provides a way of comparing the benefits of removing different pollutants by urban trees. Economic values of air purification ecosystem services provided by street trees in Warsaw were calculated based on the estimates of the amount of pollutants absorbed by these trees using i-Tree Eco software (as presented in section 4.1) and their unit external cost for urbanized areas in Poland (as summarized in the ExterneE research project). The results are presented in Table 4.

Table 4: Economic value of air purification ecosystem services provided by street trees in Warsaw

	NO_2	SO_2	$PM_{2,5}$
Total economic value of air purification ecosystem services provided by all street trees (EUR/year)	84 365–189 322	14 521	65 678–106 551
Average total economic value of air purification ecosystem services provided by a single street tree (EUR/year)	0.6–1.3	0.1	0.4–0.7

It can be seen that the most valuable benefit provided by the trees in Warsaw in terms of removing different air pollutants was due to their absorbing NO_2 (51.3-61.0% of the total economic value associated with that ecosystem service), followed by absorbing $PM_{2.5}$ (34.3-39.9%) and SO_2 (4.7-8.8%).

The results indicate that in total the Warsaw street trees provide air purification ecosystem services that may be valuated at between EUR 165 000 and EUR 310 000 per year, where the range represents the minimum and the maximum estimates based on the source of the air pollution data inputs (appropriate background station type - traffic station type). On average, one street tree in Warsaw provides ecosystem services worth between EUR 1.1 and EUR 2.1 per year.

5. Conclusions

In this study, i-Tree Eco software was used to estimate the annual amount of pollutants absorbed by street trees growing in Warsaw. The study focused on the potential of trees to absorb three pollutants: SO_2, NO_2, and $PM_{2.5}$. The reason for focusing on these pollutants is that there are publicly available data, which enabled the estimation of the absorption of these pollutants by urban trees. Moreover, for these three pollutants, there are estimates of external costs, which enable one to conduct a valuation of this ecosystem service.

Some studies using i-Tree Eco software have already been conducted on a smaller scale in Warsaw (Jędraszko-Macukow et al., 2018; Szkop, 2016). The added value of this study is that it analyzes the effect of the i-Tree Eco pollution model limitations in terms of its inability to take into account the spatial differentiation of air pollutants in a city.

In evaluating the sensitivity of the i-Tree pollution model to different pollution data inputs, the study revealed relatively low variation ($0.05 < CV < 0.23$) in estimated quantities obtained based on concentrations of pollutants retrieved from different air quality monitoring stations of the same type ("urban background" type stations) and relatively high variation ($0.24 < CV < 0.57$) in estimated quantities obtained on data retrieved from different types of stations ("urban background" versus "traffic").When data on air pollutant concentrations used in the model is from the "traffic" station type, trees provide air purification ecosystem services with an annual value almost twice as high (EUR 310 000) as when the data used is from "urban background" stations type (EUR 165 000). More than half (51.3-61.0%) of the value is due to NO_2 absorption by urban trees.

The study therefore shows that in i-Tree Eco projects which include trees growing in areas with different levels of pollution (both urban background and traffic areas of the city) the estimates for some trees will be substantially overestimated or underestimated if data from a single air quality monitoring station is used. Therefore, for the accuracy of estimates, it is important to ensure that appropriate air pollution data are used for running a particular type of i-Tree Eco project. Data retrieved from an "urban background" station should be used when the project is for urban background areas and data retrieved from a "traffic" station when the project is for traffic areas.

The study also shows that if the i-Tree Eco project is limited to trees growing in areas with similar levels of pollution (for example only urban background areas of the city), i-Tree Eco modeling based on data for concentrations of air pollutants retrieved from a single urban background station may not substantially affect the estimates for the trees, as long as the station is located in an area that has the same level of pollution. This applies in particular when the most representative NO_2 concentration data for the entire project area are used.

When interpreting the results of the monetary evaluation conducted in the study, one should bear in mind that they provide only fragmentary information on the value of ecosystem services provided by urban trees in Warsaw. For example, the study did not cover such ecosystem services as carbon sequestration, aesthetics, recreation, transpiration (humidity control) and shading, windbreak action and many others. Also, the air purification ecosystem service was only partially covered in the study, as the value of removing other pollutants (e.g., ozone or PM_{10}) was not investigated here.

It is important to indicate that in the paper the term "limitation of the i-Tree Eco pollution model" is being used, but it is mostly concerned with how researchers design their projects. Ultimately, the operators decide for which trees the software will calculate estimates, so it is a human component, rather than that the software itself that has created the problem. This study highlights the need for researchers to plan carefully and make good choices when conducting such research so that the program can be used to the best effect.

Developing the software without the capacity to distinguish between areas can be seen as an advantage. It makes it applicable for all types of users including greenery managers and volunteers without any scientific background. The more specific a model is the smaller the audience who can use it. This is true of every model and is not unique to i-Tree Eco.

In this context, it should also be noted that the discussed limitation may not concern all types of software users. If the user is interested only in obtaining a rough estimate of the total value for an entire city area, in which the vast majority are trees growing in urban background areas, and those growing in traffic areas constitute a negligible percentage, i-Tree Eco modeling based on air pollution data retrieved from a single urban background type station can also generate useful information.

It should be also stressed that the study carried out here is only a case study. The topic requires further investigation, particularly in terms of comparing values obtained in other cities.

Bibliography

Al-Hemoud, A., Al-Dousari, A., Al-Shatti, A., Al-Khayat, A., Behbehani, W., Malak, M., 2018. Health impact assessment associated with exposure to PM10 and dust storms in Kuwait. Atmosphere (Basel). 9. https://doi.org/10.3390/atmos9010006

Andersson, E., 2006. Urban landscapes and sustainable cities. Ecology and Society 11(1), 34. Available at: http://www.ecologyandsociety.org/vol11/iss1/art34/ (Accessed: 4 November 2019).

Aristodemou, E., Boganegra, L.M., Mottet, L., Pavlidis, D., Constantinou, A., Pain, C., Robins, A., ApSimon, H., 2018. How tall buildings affect turbulent air flows and dispersion of pollution within a neighbourhood. Environ. Pollut. 233, 782–796.https://doi.org/10.1016/j.envpol.2017.10.041

Baldocchi, D.D., Hicks, B.B., Camara, P., 1987. A canopy stomatal resistance model for gaseous deposition to vegetated surfaces. Atmos. Environ. 21, 91–101. https://doi.org/10.1016/0004-6981(87)90274-5

Baró, F., Chaparro, L., Gómez-Baggethun, E., Langemeyer, J., Nowak, D.J., Terradas, J., 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: The case of urban forests in Barcelona, Spain. Ambio 43, 466–479. https://doi.org/10.1007/s13280-014-0507-x

Bauer, J., Pérez, M.E., Olivero, S., 2016. i-Tree urban forest assessment in Santo Domingo's Colonial City. Santo Domingo. Available at: http://www.itreetools.org/resources/reports/DR_en-es/a01__iTree ColonialCity_eng_mar16.pdf. (Accessed: 4 November 2019).

Bautista, D., Peña-Guzmán, C., 2019. Simulating the hydrological impact of green roof use and an increase in green areas in an urban catchment with i-tree: A case study with the town of Fontibón in Bogotá, Colombia. Resources 8, 68. https://doi.org/10.3390/resources8020068

Beckett, K.P., Freer-Smith, P.H., Taylor, G., 2000. Particulate pollution capture by urban trees: effect of species and windspeed. Glob. Chang. Biol. 6, 995–1003.

Bettencourt, L., West, G., 2010. A unified theory of urban living. Nature. https://doi.org/10.1038/467912a

Bijad, E., Delavar, M.A., Sedighi, K., 2016. CFD simulation of effects of dimension changes of buildings on pollution dispersion in the built environment. Alexandria Eng. J. 55, 3135–3144. https://doi.org/10.1016/j.aej.2016.08.024

Blair, J., Roldan, C., Ghosh, S., Yung, S.H., 2017. Greening Rail Infrastructure for Carbon Benefits, in: Procedia Engineering. pp. 1716–1724. https://doi.org/10.1016/j.proeng.2017.04.334

Brown, C.E., 1998. Coefficient of Variation, in: Applied Multivariate Statistics in Geohydrology and Related Sciences. Springer Berlin Heidelberg, pp. 155–157. https://doi.org/10.1007/978-3-642-80328-4_13

Chaparro, L., Terradas, J., 2009. Ecological services of urban forest in Barcelona. Ballaterra. Available at: http://www.itreetools.org/resources/reports/Barcelona Ecosystem Analysis.pdf. (Accessed: 4 November 2019).

De la Concha, H., 2017. 1. De la Concha, H., 2017. Inventario del Arbolado Urbano de la ciudad de Mérida. Mérida. Available at: https://goo.gl/8rkpvk. (Accessed: 4 November 2019).

De Marco, A., Proietti, C., Anav, A., Ciancarella, L., D'Elia, I., Fares, S., Fornasier, M.F., Fusaro, L., Gualtieri, M., Manes, F., Marchetto, A., Mircea, M., Paoletti, E., Piersanti, A., Rogora, M., Salvati, L., Salvatori, E., Screpanti, A., Vialetto, G., Vitale, M., Leonardi, C., 2019. Impacts of air pollution on human and ecosystem health, and implications for the National Emission Ceilings Directive: Insights from Italy. Environ. Int. 125, 320–333. https://doi.org/10.1016/j.envint.2019.01.064

Doick, K., Handley, P., Ashwood, F., Vaz Monteiro, M., Frediani, K., Rogers, K., 2017. Valuing Edinburgh's Urban Trees. An update to the 2017 i-Tree Eco survey – a report of Edinburgh City Council and Forestry Commission Scotland. Farnham. Available at: https://www.edinburgh.gov.uk/download/downloads/id/12042/valuing_edinburghs_urban_trees.pdf. (Accessed: 2 November 2019).

Douglas, P., Hayes, E.T., Williams, W.B., Tyrrel, S.F., Kinnersley, R.P., Walsh, K., O'Driscoll, M., Longhurst, P.J., Pollard, S.J.T., Drew, G.H., 2017. Use of dispersion modelling for environmental impact assessment of biological air pollution from composting: Progress, problems and prospects. Waste Manag. 70, 22–29. https://doi.org/10.1016/j.wasman.2017.08.023

EEA, 2018. European Environmental Agency: Air Quality in Europe [WWW Document].

Eisenman, T.S., Churkina, G., Jariwala, S.P., Kumar, P., Lovasi, G.S., Pataki, D.E., Weinberger, K.R., Whitlow, T.H., 2019. Urban trees, air quality, and asthma: An interdisciplinary review. Landsc. Urban Plan. https://doi.org/10.1016/j.landurbplan.2019.02.010

Estevez, E., Lopes, N.V., Janowski, T., 2016. Smart Sustainable Cities. Reconnaissance Study 330.

ExternE, 2005. External Costs of Energy. Available at: http://www.externe.info/externe_d7/. (Accessed: 2 November 2019).

Foster, D., Duinker, P., 2017. Dalhousie University. Halifax. Available at: http://www.itreetools.org/resources/reports/FosterDuinker_2017_iTreeEcoForHalifax_Feb2017.pdf. (Accessed: 2 November 2019).

Gardner, J., McDuie, M., Boyle, E., 2017. Valuing the Waite Arboretum, South Australia. Adelaide.

Graça, M.S., Gonçalves, J.F., Alves, P.J.M., Nowak, D.J., Hoehn, R., Ellis, A., Farinha-Marques, P., Cunha, M., 2017. Assessing mismatches in ecosystem services proficiency across the urban fabric of Porto (Portugal): The influence of structural and socioeconomic variables. Ecosyst. Serv. 23, 82–93. https://doi.org/10.1016/j.ecoser.2016.11.015

Hiemstra, J., Schoenmaker - van der Bijl, E., Tonneijck, A.E.., 2008. Bomen een verademing voor de stad. Boskoop.

Hirabayashi, S., Kroll, C.N., Nowak, D.J., 2015. i-Tree Eco dry deposition model descriptions. New York. Available at: https://www.itreetools.org/eco/resources/iTree_Eco_Dry_Deposition_Model_Descriptions.pdf. (Accessed: 2 November 2019).

Hotte, N., Mahony, C., Nelson, H., 2016. The principal-agent problem and climate change adaptation on public lands. Glob. Environ. Chang. 36, 163–174.

Hubacek, K., Kronenberg, J., 2013. Synthesizing different perspectives on the value of urban ecosystem services. Landsc. Urban Plan. https://doi.org/10.1016/j.landurbplan.2012.10.010

Hutchings, T., Lawrence, V., Brunt, A., 2012. Estimating the Ecosystem Services Value of Edinburgh's Trees. Farnham. https://www.itreetools.org/documents/317/Edinburgh_iTree_Report.pdf (Accessed: 2 November 2019).

Jędraszko-Macukow, M., Sitarski, M., Szczepanowska, B., Sudra, P., Carewicz, N., 2018. Usługi ekosystemowe drzew i krzewów w Parku Praskim określone za pomocą modelu I-Tree Eco. Człowiek i Środowisko 41, 5–23. Available at: http://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-d1b62d6d-e830-44fc-966a-38b33d46ba73 (Accessed: 2 November 2019).

Jones, B.A., Goodkind, A.L., 2019. Urban afforestation and infant health: Evidence from MillionTreesNYC. J. Environ. Econ. Manage. 95, 26–44. https://doi.org/10.1016/j.jeem.2019.03.002

Kiss, M., Takács, Á., Pogácsás, R., Gulyás, Á., 2015. The role of ecosystem services in climate and air quality in urban areas: Evaluating carbon sequestration and air pollution removal by street and park trees in Szeged (Hungary). Morav. Geogr. Reports 23, 36–46. https://doi.org/10.1515/mgr-2015-0016

Lefrançois, C.B., 2015. Designing effective stormwater management policies : The role of the urban forest and impervious cover in Vancouver, B.C. (Master's thesis). The UBC School of Community and Regional Planning (SCARP). https://doi.org/10.14288/1.0300042

Lovett, G.M., 1994. Atmospheric deposition of nutrients and pollutants in North America: An ecological perspective. Ecol. Appl. 4, 629–650. https://doi.org/10.2307/1941997

Medrano, O.A.A., 2019. Measuring the benefits of urban nature-based solutions through quantitative assessment tools (Master's thesis). Universiteit Utrecht.

Meléndez-Ackerman, E., Trujillo, A., Nytch, C., Ramse, M., Branoff, B., Olivero-Lora, S., 2018. Ecological vulnerability of urban green infrastructure to Hurricanes Irma and Maria in Puerto Rico. Puerto Rico. Available at: http://www.itreetools.org/resources/reports/EcoServices-PostMaria_2018CDK-IITF.pdf (Accessed: 5 November 2019).

Morani, A., Nowak, D.J., Hirabayashi, S., Calfapietra, C., 2011. How to select the best tree planting locations to enhance air pollution removal in the MillionTreesNYC initiative. Environ. Pollut. 159, 1040–1047. https://doi.org/10.1016/j.envpol.2010.11.022

Nowak, D.J., 2019. The Atmospheric System: Air Quality and Greenhouse Gases, in: Understanding Urban Ecology. Springer International Publishing, Cham, pp. 175–199. https://doi.org/10.1007/978-3-030-11259-2_8

Nowak, D.J., 2018. Améliorer les forêts citadines à travers l'évaluation, la modélisation et le suivi. Unasylva 69, 30–36.

Nowak, D.J., 1996. Estimating Leaf Area and Leaf Biomass of Open-Grown Deciduous Urban Trees. For. Sci. 42, 504–507.

Nowak, D.J., Hirabayashi, S., Bodine, A., Greenfield, E., 2014. Tree and forest effects on air quality and human health in the United States. Environ. Pollut. 193, 119–129. https://doi.org/10.1016/j.envpol.2014.05.028

Nowak, D.J., McHale, P.J., Ibarra, M., Crane, D., Stevens, J.C., Luley, C.J., 1998. Modeling the effects of urban vegetation on air pollution, in: Gryning, Sven-Erik; Chaumerliac, N. (Ed.), Air Pollution Modeling and Its Application XII. Plenum Press, New York, pp. 399–407.

Pauleit, S., Duhme, F., 2000. GIS assesment of Munich's urban forest structure for urban planning, Journal of Arboriculture. 26(3), 133–141

Plummer, M.L., 2009. Assessing benefit transfer for the valuation of ecosystem services. Front. Ecol. Environ. https://doi.org/10.1890/080091

Raum, S., Hand, K., Hall, C., Edwards, D., O'Brien, L., Doick, K., 2019. Achieving impact from ecosystem assessment and valuation of urban greenspace: The case of i-Tree Eco in Great Britain. Landsc. Urban Plan. 190, 1–17. https://doi.org/10.1016/j.landurbplan.2019.103590

Rogers, K., Sacre, K., Goodenough, J., Doick, K., 2015. Valuing London's Urban Forest. Results of the London i-Tree Eco Project. London. Available at: https://www.treeconomics.co.uk/wp-content/uploads/2018/08/London-i-Tree-Report.pdf. (Accessed: 4 November 2019).

Scholz, T., Hof, A., Schmitt, T., 2018. Cooling effects and regulating ecosystem services provided by urban trees - Novel analysis approaches using urban tree cadastre data. Sustainability 10, 712. https://doi.org/10.3390/su10030712

Siedlarczyk, E., Winczek, M., Zięba-Kulawik, K., Wężyk, P., 2019. Smart green infrastructure in a smart city - The case study of ecosystem services evaluation in Krakow based on i-Tree ECO software. Geosci. Eng. 65, 36–43. https://doi.org/10.35180/gse-2019-0010

Szkop, Z., 2016. An evaluation of the ecosystem services provided by urban trees: The role of Krasiński Gardens in air quality and human health in Warsaw (Poland). Environ. Socio-economic Stud. 4, 41–50. https://doi.org/10.1515/environ-2016-0023

Wu, J., Wang, Y., Qiu, S., Peng, J., 2019. Using the modified i-Tree Eco model to quantify air pollution removal by urban vegetation. Sci. Total Environ. 688, 673–683. https://doi.org/10.1016/j.scitotenv.2019.05.437

Zhong, S., Zhou, L., Wang, Z., 2011. Software for environmental impact assessment of air pollution dispersion based on ArcGIS, in: Procedia Environmental Sciences. Elsevier B.V., pp. 2792–2797. https://doi.org/10.1016/j.proenv.2011.09.433

Zhou, M., He, G., Liu, Y., Yin, P., Li, Y., Kan, H., Fan, Maorong, Xue, A., Fan, Maoyong, 2015. The associations between ambient air pollution and adult respiratory mortality in 32 major Chinese cities, 2006-2010. Environ. Res. 137, 278–286. https://doi.org/10.1016/j.envres.2014.12.016

Żylicz, T., 2017. Pricing urban trees. Aura 11, 16–17. Available at: http://coin.wne.uw.edu.pl/tzylicz/1711aura.pdf (Accessed: 5 November 2019).

ZZM, 2017. Urban Greenery Board of Warsaw. Available at: http://zzw.waw.pl/baza-wiedzy (Accessed: 4 November 2019).