Avoided Surface Runoff as an Ecosystem Service: the Case Study of a Green Area in Turin (IT)

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Avoided Surface Runoff as an Ecosystem Service: the Case Study of a Green Area in Turin (IT)

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Abstract

The following work is part of the broader panorama of the relationship between man and nature, with a point of view looking to the future: the study of ecosystem services provided by nature and, in particular, by vegetation, is taking on a role gradually more and more consistent, in relation to the need of climate change adaptation.
And what better representation of the human footprint than city: the urban scale is deepened in this project, through an investigation aimed at quantifying a specific ecosystem service: the avoided surface runoff. The reference area is a park of about 35 hectares located in the suburbs of Turin city, inserted within the relative metropolitan area: the tool used is a specific software suite for quantifying the ecosystem services provided by vegetation. In particular, the evaluation of the avoided surface runoff was carried out relying on two different *i-Tree* programs: using the *Eco* tool, aimed at studying the environmental benefits produced by an urban forest, the focus was on the quantity of water that trees are able to subtract, through interception, from the water runoff that has the city sewers as its final destination, while *i-Tree Hydro*, a hydrological model specific for vegetation, allowed to quantify the total amount of surface runoff interesting the green area, taking into account the whole vegetative sector. Linking the final results of both *i-Tree* programs, the study aims to discuss the role of the park in the water management of the sewerage system and, at the same time, make a reflection on the relationship between urban green spaces within built-up areas and the reduction of hydrogeological risk.

Keywords surface runoff; ecosystem services; urban green areas; water balance

1. INTRODUCTION

Current population growth, increased levels of pollution and over-exploitation of natural resources raise questions about the state of ecosystems and threaten the delicate relationship between man and nature (Busca et al., 2021). These phenomena are, and will be, amplified by the climate change, which is deeply accelerating: in the last 100 years, the quantity of glaciers present on Earth has decreased considerably with a consequent rise of of the sea level between 10 and 20 centimeters, according to the Intergovernmental Panel on Climate Change (IPCC) (W1).

Cities represent the main collectors of these consequences, and therefore the urban population, currently more then 50% worldwide and destined to reach 68% by 2050 (United Nations, 2019). Furthermore, cities nowadays represent the human settlement type that most characterizes the present historical period, framing itself as a nerve center for human activities and for the alteration of the environmental balances: urban centers, in fact, occupy only 3% of the planet's surface but consume about 75% of natural resources (water, food, soil materials), leading to a reduction in the soil functionality and causing alterations in the ecological characteristics of the landscape and the degree of biodiversity. Substantially, cities alter natural resources and lead to their overexploitation, producing more than 70% of global greenhouse emissions (Fragkias et al., 2013).

In this context, various solutions are currently available in order to fight and mitigate the negative processes mentioned above, starting with climate change: a strategy is that of Ecosystem Services (ES) restoration (Zerb et al., 2013), i.e. the process of restoring habitats and ecosystem functions through the retrieval of lands and waters on which flora and fauna depend. ES, initially defined by the Millennium Ecosystem Assessment (MA) and then subsequently classified in different ways, as the Common International Classification of Ecosystem Services (CICES), represent the components of natural capital that provide products, services and intangible benefits to mankind (Haines-Young and Potschin, 2018; Millennium Ecosystem Assessment, 2005). In general, there are different types: from services for the supply of raw materials (fresh water, food) to intangible services that contribute to improving the social well-being of the population (for example, an equipped urban green area represents a space for social inclusion). In this work, regulatory ecosystem services are considered, i.e. those with the function of regulating one or more ecosystem processes and, in particular, a service linked to the control of water cycle of an urban area: the avoided surface runoff, i.e. the free flow of rainwater on the soil surface.

Its volume and its features depend on different variables, including the characteristics of rainfall events (intensity, duration, distribution), land use, soil cover and slope (Shanmukha et al., 2018). In the cities, during rainfall events surface runoff is generally collected in urban drainage systems, which then, subsequently, carry the collected water into the relative receiving water body. In this regard, many of the problems related to urban surface runoff water depend on the processes of continuous increase in the waterproofing of urban surface (Booth, 1991) in relation to a continuous grow in the urban population. One of the advantages provided by the presence of green areas within cities is to modify the land cover distribution by increasing the percentage of permeable urban surface, which means counteracting the excessive waterproofing of urban soil due to overbuilding.

In this paper, the ability of some urban green areas to increase urban resilience by minimizing the flow of water directed to the various collection systems is analyzed in depth through a specific ES quantification software for vegetation: through mechanisms of storage, infiltration, evapotranspiration detailed in Chapter 2. Chapter 3 reports the results of a project aimed at quantifying the benefits produced by an Italian city park with regard to the avoided water runoff, in order to lighten the water drainage structures of the Municipality of Turin (Italy). This paper deals with some SDGs defined in Agenda 2030 by United Nations (UN) and, in particular, contribute to reach goal n. 3 “Good health and well-being” ensuring healthy lives and goal n. 11 “Sustainable cities and communities” through the protection and the restoration of ecosystems.

2. METHODOLOGY

Results shown in this paper are based on the implementation of the software suite *i-Tree* and, in particular, through the program *i-Tree Hydro. Hydro* is an application based on an urban hydrology model specific for vegetation and allows to simulate the effects of changes in tree cover at the urban level on local hydrology. Generally, the water balance refers to Eq. [1]:

$$PR = VET + VI + S + PI + PF + IF + SF + GET \qquad [1]$$

PR is the precipitation; VET and GET represent respectively vegetation and ground evapotranspiration; VI stands for the vegetation interception; S is the storage in soil depressions; PI represents infiltration on permeable soil; PF, IF and SF are respectively permeable, impermeable and surface runoff. The unit of measure of all terms of Eq. [1] is millimeter.

The reference model is the Urban Forest Effects Hydrological (UFORE-Hydro) model, topographically based and developed through the OBJTOP (Object-oriented, Topographic) structure, and uses algorithms which work with interception, storage, infiltration, evaporation and runoff data (Wang et al., 2008). The studied version envisaged the use of an urban scheme of soil-vegetation-atmosphere exchanges represented by vertical layers.

Briefly, the fundamental equations underlying the model will be reported. As for the rainfall interception, Eq. [2] is the reference equation, referring to a deterministic algorithm theorized by Rutter et al. (1971, 1975) and, in particular, to the variation proposed by Valente et al. (1997) which allows to consider a sparse distribution of vegetation.

$$\frac{\Delta C}{\Delta t} = P - R - E \qquad [2]$$

C, in meters, is equal to the depth of the rain on the unit canopy at time *t*; *P* is the precipitation above the canopy; *R* is the precipitation under the canopy reaching the ground and *E* is the evaporation rate. The unit of measure is meter per second; Δt, instead, represents the time interval of the simulation.

$$S = S_L \cdot LAI \qquad [3]$$

The storage of water *S* is expressed by Eq. [3], where *LAI* is the Leaf Area Index and S_L, in meters, represents the maximum specific leaf storage capacity: in this project, it has been taken as default value of 0.0002 meters (Dickinson, 1984).

Evaporation affects the amount of water intercepted and stored. *E*, in meters per second, is defined as the evaporation flow according to Eq. [4] (Noilhan and Planton, 1989; Deardorff, 1978), where E_p is the potential evapotranspiration. For further information about potential evapotranspiration, the paper of Wang et al. (2008) should be taken as reference.

$$E = \left(\frac{C}{S}\right)^{2/3} \cdot E_p \qquad [4]$$

UFORE-Hydro divides the water percolated from vegetation on the surface in ponding, infiltration and runoff (Wang et al., 2008) through the combination of infiltration and saturation ideas expressed by TOPMODEL with the modified Green-Ampt theory. The infiltration rate is equal to the derivation over time of the cumulative infiltration *I*, according to Eq. [5], where *Z* represents the soil depth in meters, $\Delta\psi$ is the wetting front suction in meters and K_z is the hydraulic conductivity in meters per second. Hydraulic conductivity decays exponentially with soil depth, according to Beven (1984).

$$i = \frac{dI}{dT} = \frac{\Delta\psi + Z}{\int_{Z=0}^{Z=Z} \frac{dZ}{K_Z}} \qquad [5]$$

The outflow per unit watershed area in meters per second (q_{tot}) is given by the sum of the subsurface flow ($q_{subsurface}$), the surface flow ($q_{overland}$) and the flow of impermeable areas ($q_{impervious}$), as in Eq. [6].

$$q_{total} = q_{subsurface} + q_{overland} + q_{impervious} \qquad [6]$$

The overland runoff refers to permeable soils and is given by the sum of the surface flows due to excess of saturation and excess of infiltration, according to the TOPMODEL theory in Eq. [7], where A_{sat} represents the saturated area and *A* is the total slope area while P_W is the spatially weighted precipitation above and below the canopy.

$$Q_{overland} = \frac{A_{sat}}{A} \cdot P_W \qquad [7]$$

The subsurface flow, on the other hand, is considered as the flow of water that moves from the saturated areas of the soil.

Output data will concentrate on the characteristics relating to different types of runoff produced by the green area.

i-Tree Eco, therefore, is a tool of the suite aimed at providing information on the structure of urban greenery and its environmental effects on the surrounding context and can furnish estimates for different ES, including surface water runoff avoided thanks to the vegetation, i.e. the amount of surface runoff without any trees minus the amount of surface runoff with current tree cover. *I-Tree Eco* bases the estimate of net avoided runoff on simplified *Hydro* simulations and, in the next steps, the main equations for the calculation are reported. The estimate of avoided runoff *S* is obtained from the difference between annual overland surface runoff of two different scenarios: (i) actual scenario, i.e. the study area considering vegetation; (ii) hypothetical scenario, the same study area without vegetation, as in Fig. 1, and can be calculated as in Eq. [8].

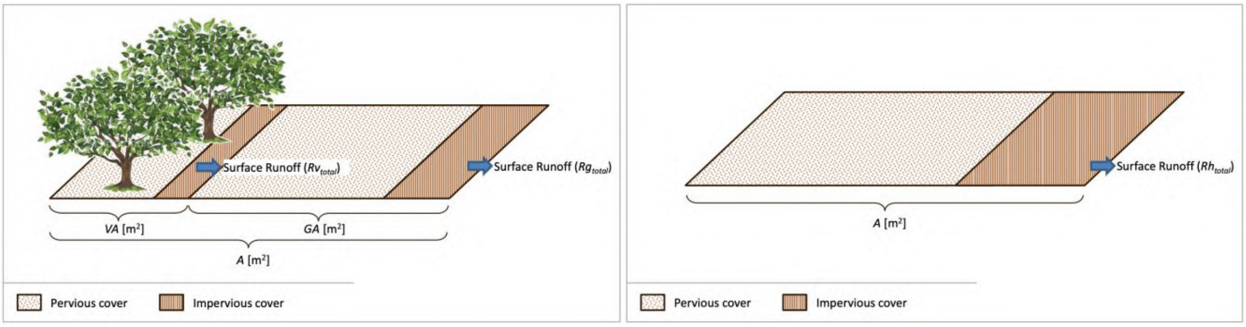

Figure 1. Example of actual (on the left) and hypothetical (on the right) scenario (Hirabayashi, 2013)

$$S = Rh_{total} - Ra_{total} \qquad [8]$$

Rh_{total}, in cubic meters. represents runoff from impervious cover of the hypothetical scenario and follows Eq. [9], where *A* is the total area in square meters and Rg_t is the overland runoff at time *t*, in meters.

$$Rhtotal = \sum Rg_t \cdot A \cdot 0.255 \qquad [9]$$

The coefficient 0.255 comes from Nowak and Greenfield (2012), where it has been assumed that 25.5% of the urban space is covered with impermeable soil. Therefore, the total runoff from the selected area of the actual scenario Ra_{total} is given by the sum of runoff from impervious cover in the area covered by vegetation and in the area not covered by vegetation (see Fig. 1, on the left).

$$Ra_{total} = Rv_{total} + Rg_{total} = \sum Rv_t \cdot VA \cdot 0.255 + \sum Rg_t \cdot GA \cdot 0.255 \qquad [10]$$

The calculation of Ra_{total} is shown in Eq. [10], where *VA* is the area covered by vegetation while *GA* is the complementary area, not covered by canopy, both in square meters; Rv_t and Rg_t are respectively the overland runoff in the *VA* and in the *GA* at time *t*, both in meters.

3. STUDY AREA AND RESULTS

3.1 Study Area

The work has been focused on “Le Vallere” Park, an extensive semi-urban green area located between the Municipality of Moncalieri and the Municipality of Turin (Italy, N W). Turin covers an area of 130 square kilometers with a population of about 850 thousand inhabitants, at a height of 239 meters above sea level; the average temperature of 12 Celsius degrees and, according to Köppen and Geiger, its climate is classified as Cfa, humid subtropical climate. The studied area of the park has an extension of about 340,000 square meters and is characterized by an alternation of intensive forage cultivation and clearings full of trees.

The meteorological data considered refer to two different stations:

i. For *i-Tree Eco*, it was necessary to enter the *Torino-Brico della Croce* weather station (45°02’01.86’’N 07°43’56.58’’E) as it is the closest one to the area of interest among those validated by the program;
ii. For *i-Tree Hydro* it was possible, however, to enter data manually, therefore the *Torino-Vallere* weather station (45°01’01.13’’N 07°40’26.03’’E) present within the park was chosen; the annual precipitation referring to 2019 is 915 millimeters,

3.2 Land Cover and Input Data

The software needs a certain number of input data; in particular, for the purpose of the project, *i-Tree Eco* has required: (i) meteorological data (precipitation, temperature) with an hourly frequency referring to a reference year; (ii) data collected *in situ*, through inspections, relating to the vegetation (use and ground cover, characteristics of trees); (iii) unit benefit prices, in order to give an economic estimate of the ecosystem service considered (in this case, the data entered is that of avoided runoff, assumed by default equal to 1.902 euros per cubic meter[a]. *I-Tree Hydro*, on the other hand, has required the following data: (i) land cover data for each category considered; (ii) hydrological parameters relating to the study area; (iii) pollutant concentration coefficients.

With regard to the outputs of water interest, to which this project is addressed, the definition of the soil cover distribution, obtained through the use of the supplementary program *i-Tree Canopy* (W2), is fundamental. Table 1 shows land cover distribution, in square meters and as a percentage.

Table 1. Land Cover distribution of the park from *i-Tree Canopy*

ABBREVIATION	COVER CLASS	AREA±SE (M^2)	%±SE
H	Grass/Herbaceous	196,200±4,700	57.15±1.37
IC	Impervious Cover	12,900±1,800	3.77±0.53
TI	Tree – Impervious	5,500±1,200	1.62±0.35
BS	Bare Soil	12,100±1,800	3.54±0.51
TP	Tree-Pervious	116,500±4,500	33.92±1.31
W	Water	0±0	0.00±0.00
TOT		343,200	100.00

As shown in Tab.1, the most widespread cover is the permeable soil, for a total of about 90% between *Herbaceous* and *Tree-Pervious*, while the impermeable ground covers not even 6% of the total surface considered: these data have a considerable weight on the results shown below.

[a] *i-Tree Eco* is also able to produce monetary estimates starting from the quantified environmental benefits. In the case of avoided runoff, the unit benefit value has been maintained to the default value given by the program, i.e. the US national average value converted to euro: it is based on the U.S. Forest Service’s Community Tree Guide Series (W3).

3.3 Results

By reconnecting to Eq. [6] *i-Tree Hydro*, among the various outputs it is able to provide, estimates the total quantity of outflow (*Total Flow*) and divides it into three components: (i) *Impervious Flow*; (ii) *Pervious Flow*; (iii) *Base Flow*. From Figure 2, it results that almost 99% of the runoff generated belongs to permeable type, i.e. flow due to excess infiltration and excess saturation, a direct consequence of the characteristics of the area and distribution of land cover. Only just over 1,500 cubic meters per year are classified as impermeable runoff, intrinsically linked to the few and occasional portions of surface used for parking or built-up areas, and the quantity of *Base Flow* infiltrating in the aquifer, less than 1,000 cubic meters, is due to the characteristic slow response of the flow type.

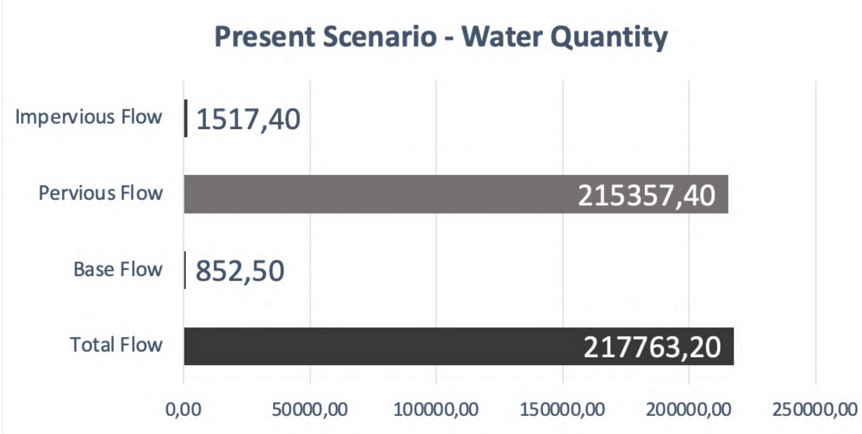

Figure 2. *Water Quantity* outputs from *i-Tree Hydro*, in square meters

On the other hand, since it is not a specific program about hydrology like *Hydro* but which focuses on all aspects related to the presence of vegetation and its environmental impact, *i-Tree Eco*, among its various functions, estimates the avoided water runoff thanks to the interception by vegetation (trees and shrubs), through infiltration promoted by their root systems and storage.

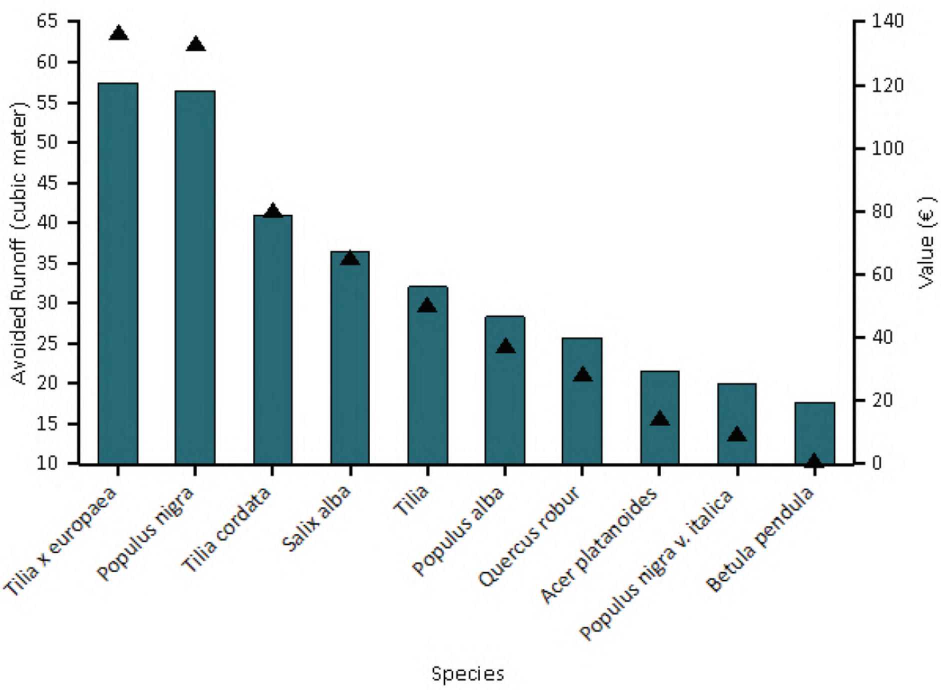

Figure 3. Avoided runoff (points) and economic value (bars) for species with greatest overall impact on runoff, from *i-Tree Eco*

The estimated quantity of avoided runoff promoted by the park is 386 cubic meters per year, associated with an economic value of 730 euros[b], based on an annual rainfall amount in the park of 32.2 centimeters. To give an idea of the park's ability to reduce the hydrogeological risk associated with the area in which it is located, the estimated volume is equivalent to almost four home swimming pools[c]. Figure 3 reports an exported graph from the report produced by *i-Tree Eco*, which shows the breakdown of avoided runoff by specie, considering the main specie types of the park; through such analysis, the software allows to investigate aspects related to the effectiveness of the species spread within the park and provides a useful tool for territorial planning.

4. DISCUSSION AND CONCLUSIONS

Starting from a project aimed at quantifying the ecosystem services provided by "Le Vallere" park in collaboration with the relevant management public institution of the area, the paper has deepened a specific one, linked to the management of urban water runoff. Through the use of *i-Tree Hydro*, software based on a specific hydrological model for evaluating the effects of the vegetation on the quantity and quality of water, a general picture of the characteristics of the outflow generated by the area was obtained. It was therefore possible, starting from meteorological data and the knowledge of land cover types, to know the distribution of the outflow between three different categories (*pervious, impervious and base flow*), which has provided useful information for understanding the water stress that the park generates on the urban drainage system within which it is inserted. Once these results were obtained and assimilated, the work has continued by introducing *Eco* program, a collection of forest analysis tools aimed at quantifying the environmental benefits produced by vegetation, part of the *i-Tree* software suite together with *Hydro*. Among the various features implemented on the green area considered, the paper has focused on the "avoided runoff" SE, which quantifies the amount of surface water runoff that vegetation, through interception, infiltration and storage processes, is able to save. It is possible to imagine the data obtained as an estimate of the volume of rainwater that the park has "removed" from the urban drainage system and, then, from the relative receiving water body, contributing to reduce the water stress on them, especially during extreme weather events. *Eco* also has given a monetary estimate of this benefit, based on unitary economic data referring to an estimated cubic meter of avoided outflow in the United States.

The examined portion of "Le Vallere" park, with an extension of 343,300 square meters and with an average annual precipitation data referring to 2019 of 915 millimeters, produced an annual flow of approximately 218 thousand cubic meters, of which only 1,500 come from impermeable areas and the remaining part is mainly associated with permeable runoff (*i-Tree Hydro*). It is interesting to compare these data with the avoided runoff estimate produced by *Eco*, equal to 386 cubic meters per year: the latter data, although with a beneficial connotation, appears to be modest, even more referring to the outflow volumes that annually affect the area. In this regard, it should be emphasized that *Eco* is not a specific software for the hydrology of vegetation and soil and that, for the quantification of this ecosystem service, it is based on a simplified *Hydro* model; in *Eco*. In addition, only the processes related to vegetation (trees and shrubs) play an active role in the calculation of avoided runoff, in order to limit the analysis in search of the benefit offered by the presence of trees and shrubs alone. This means that the contribution given by the processes affecting the ground (infiltration, evapotranspiration, etc.) are not considered and that, paradoxically, by studying a ground consisting only of grass, the software would return an avoided runoff value equal to 0.

Finally, reflecting on the economic estimate of about 730 euros associated with this ES, it is clear how much the political and social interest and the enhancement of solutions aimed at reducing water stress and hydrogeological risk, especially in the urban context, are still not relevant. The unit benefit price, i.e. the default value of *i-Tree* and referred to U.S. context, of 1.9 euros per cubic meter of surface runoff saved is a good indicator of the current difficulty in associating an economic value to ESs, as result of a considerable negligence in terms of economic (as well as environmental) damage, generated by extreme flood events increasingly frequent in the city.

The project will have two future developments: the use of other ES evaluation tools, in order to compare the results obtained and overcome the limits met in this analysis; an in-depth study on the economic issue, aimed at seeking more detailed information on the monetary quantification of this ES and at understanding the process through which a single cubic meter of water runoff saved to the sewerage system can generate savings on the economic balance of the Municipality, of the neighboring activities and of the inhabitants.

[b] The monetary value has been calculated, by the program, considering the amount of total avoided runoff volume (cubic meters) and the unit benefit price defined in Chapter 3.2.
[c] Considering a swimming pool with dimensions of 10x5x2 meters.

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6. REFERENCES

Beven, K. (1984). Infiltration Into a Class of Vertically Non-Uniform Soils. *Hydrological Sciences Journal*, 29(4), 425-434.
Booth, D.B. (1991). Urbanization and the natural drainage system – impacts, solutions, and prognoses. *Northwest Environmental Journal*, 7, 93-118.
Busca, F., Tinivella, I. and Revelli, R. (2021). Urban sustainability: the role of ecosystem services provided by an Italian green infrastructure. *GEAM. Geoingegneria Ambientale e Mineraria,* 163-164, 46-55.
Deardorff, J.W. (1978). Efficient Prediction of Ground Surface Temperature and Moisture With Inclusion of a Layer of Vegetation. *Journal of Geophysical Research,* 83, 1889-1904.
Dickinson, R.E. (1984). Modeling Evapotranspiration for Three-Dimensional Global Climate Models. *Climate Processes and Climate Sensitivity*, Geophysical Monograph Series, 29, 58-72.
Fragkias, M., Lobo, L., Strumsky, D. and Seto, K.C. (2013). Does size matter? Scaling of CO2 emissions and US urban areas. *PloS one,* 8(6), e64727.
Haines-Young, R. and Potschin, M.B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.
Hirabayashi, S. (2013). i-Tree Eco Precipitation Interception Model Descriptions.
Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.
Noilhan, J. and Planton, S. (1989). A Simple Parameterization of Land Surface Processes for Meteorological Models. *Monthly Weather Review*, 117(3), 536-549.
Nowak, D.J. and Greenfield, E.J. (2012). Tree and impervious cover in the United States. *Landscape and Urban Planning*, 107, 21-30.
Rutter, A.J., Morton, A.J. and Robins, P.C. (1975). A Predictive Model of Rainfall Interception in Forests. II. Generalization of the Model and Comparison With Observations in Some Coniferous and Hard-Wood Stands. *Journal of Applied Ecology.* 12. 367-380.
Rutter, A.J., Morton, A.J. and Robins, P.C. (1971). A Predictive Model of Rainfall Interception in Forests. I. A Derivative of the Model From Observations in a Plantation of Corsican Pine. *Agricultural Meteorology,* 9, 367-384.
Shanmukha Srinivas, G., Satyanarayana Moorthy, D.V., Yaswanth Kumar, Y. and Jyothi, P. (2020). Surface Runoff Estimation using RS and GIS – A Case Study of Swarnamukhi River, India. *International Journal of Science and Research (IJSR)*, 9, 780-784.
United Nations (2019). Yearbook of the United Nations 2014. *Yearbook of the United Nations.*
Valente, F., David, J. and Gash, J.H.C. (1997). Modeling Interception Loss for Two Sparse Eucalypt and Pine Forests in Central Portugal Using Reformulated Rutter And Gash Analytical Models. *Journal of Hydrology*, 190, 141-162.
Wang, J., Endreny, T.A. and Nowak, D.J. (2008). Mechanistic simulation of tree effects in an urban water balance model. *JAWRA Journal of the American Water Resources Association*, 44(1), 75-85.
Zerb, S., Steffenhagen, P., Parakenings, K., Timmermann, T., Frick, A., Gelbrecht, J. and Zak, D. (2013). Ecosystem Service Restoration after 10 Years of Rewetting Peatlands in NE Germany. *Environmental management*, 51(6).

W1. https://www.ipcc.ch/ Last accessed: 17/02/2022
W2. https://canopy.itreetools.org/ Last accessed: 18/02/2022
W3. https://www.fs.fed.us/psw/topics/urban_forestry/products/tree_guides.shtml Last accessed: 20/02/2022

