Chapter 5

Water Runoff and Catchment Improvement by Nature-Based Solution (NBS) Promotion in Private Household Gardens: An Agent-Based Model

Rembrandt Koppelaar, Antonino Marvuglia, and Benedetto Rugani

Abstract Nature-based solutions (NBS) such as rainwater gardens and permeable paving can be deployed as an alternative to conventional urban gardens to improve cities' resilience against increasing rainfall. This study describes the application of an agent-based model (ABM) to assess the role of private gardens toward the enhancement of water management by households. The ABM simulates the process of switching from "gray" (i.e., paved) to green gardens, taking into account the effect of "soft" (garden networks and gardening workshops) and "hard" (monetary) incentives. The ABM is supported by a water balance model to consider the effect of rainfall on soil water retention. Four different cities in Europe were analyzed: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). The results demonstrate that greening private gardens can generate impact on water run-off and catchment in cities in the order of 5–10%, reaching picks up to 20% in certain cases. While the proposed model is not devoid of limitations, the results provide useful insights in the ways different instruments (e.g., municipal subsidies and knowledge support) could assist with the greening of private gardens for NBS promotion to respond to cities' water management challenges.

Keywords Green gardens · Urban green solutions · Individual-based simulation · Water retention · Netlogo · Gardens management

R. Koppelaar (✉)
Ecowise Ekodenge Ltd, London, UK
e-mail: rembrandt.koppelaar@eco-wise.co.uk

A. Marvuglia · B. Rugani
Luxembourg Institute of Science and Technology (LIST), Belvaux, Luxembourg
e-mail: antonino.marvuglia@list.lu; benedetto.rugani@list.lu

5.1 Introduction

Heavy rain showers cause serious water management problems in urban areas, when sewage systems overflow, streets are submerged and lower-lying buildings and basements face the risk of nuisance or even damage resulting from flooding (Atta-ur-Rahman, Parvin, Shaw, & Surjan, 2016; Eldho, Zope, & Kulkarni, 2018; Shepherd, 2013). An increase in soil sealing in urban areas has been acknowledged as an important factor in these urban water management problems (Ferreira et al., 2019). Increased soil-sealing is the result of increasing land use for urbanization not only due to population growth and urban sprawl but also of a trend to pave private gardens.

Urban water management is not only just a public issue but also increasingly one in which a variety of private actors have a role. Due to the share of privately owned land through homeownership, households can play an important role in preventing these water management problems. Homeowners could reduce soil sealing by changing their “gray” (i.e., paved) garden into a permeable, green garden with plants and grass that allows for better absorption of rainwater. This raises the question on how private households that have a yard in the back or in front of their homes could be encouraged to green their paved garden.

Based on the literature, three important conditions informed by social practice theory (Reckwitz, 2002) can be distinguished as relevant to the practice of garden transformation: (i) *Willingness to change*, that is, people’s proneness to change and how it is affected by social, physical, institutional, and economic conditions); (ii) *Competences*, that is, ability to change (what people need in order to be able to change, in terms of knowledge, relational and financial resources, time, and physical skills); and (iii) *Meaning*, that is, what motivations drive people to adopt this change, such as environmental values, financial values, comfort-related values, social or even religious values, and social status. Such dynamics of behavioral change are not straightforward. The value that a private garden represents varies substantially across people, and different types of behavioral change need different supportive measures to enhance the likelihood of successful and lasting transformation. Firstly, a need exists to consider the (symbolic) meanings, uses, and values of the yard and related practices to the householders. Secondly, the extent should be considered to which those meanings are maintained when (part of) the yard is greened, and perhaps complemented or replaced by new meanings over time, through supportive interventions. These factors affect the willingness to change; for example, if people are keen on gardening and they spend considerable time doing so, this is the best guarantee for them having a green garden (Beumer, 2018; Kullberg, 2016).

Changing one’s gray backyard into a (partially) green garden, involves both one-shot behaviors (the conscious decision to take out tiles and plant vegetation, often asking for an investment of money, effort, or time) and routine behaviors (adopting new routines of watering and maintaining this vegetation, or even gardening practices, which often need to be supported by the social, institutional, and physical

environment). It then becomes important that peers also adopt these routines, that norms and rules do not work against these routines and that the physical environment is not discouraging. The theoretical background concerning those hypothetical values, solutions, and behavioral changes is described in a deliverable of the project Nature4Cities (<https://www.nature4cities.eu/>), a European H2020 project that funded the present research (Nature4Cities, 2019). The aim of this work is analyzing them quantitatively, thus enabling comparisons of decisional impacts in terms of their social, environmental, and economic aspects. An agent-based modelling approach was deployed to accomplish this objective.

5.2 Methodology

In general, an agent-based model (ABM) allows for a fine representation of real world based on its object-oriented approach, where individuals can be simulated with their individual characteristics, as well as with their group behaviors arising from interactions among individuals (Marvuglia, Navarrete Gutiérrez, Baustert, & Benetto, 2018). As such, ABMs make it possible simulating heterogeneity among societal groups, due to socioeconomic factors such as age, lifestyle, preferences, and motivational factors. This renders ABMs a suitable methodology to study a wide range of behavioral and socioeconomic factors relevant for nature-based solutions (NBS) decisions, such as health, quality of life, social cohesion, environmental justice, economic value, and so forth. Another advantage of ABM is that spatial information of the urban environment and its relationship to people can be readily incorporated based on Geographical Information Systems (GIS) collated data, which is meaningful for purposes of evaluating heterogeneity between NBS spaces, buildings with NBS, and other structures associated with urban NBS networks.

This study is based on an ABM built in the popular Netlogo platform (version 6.0.4: <https://ccl.northwestern.edu/netlogo/>). Private garden owners are represented as a set of individual objects (called “agents”) enforcing a set of decision mechanisms directing them toward the enhancement of water management at the household level. NBS such as rainwater gardens, infiltration gardens, and permeable paving are seen as an intervention that transforms gardens covered with impermeable tiles, bricks, or other paved infrastructure into those that can absorb and retain water that is put to use for plant growth, for urban water and nature management purposes. The scenario focus is on gardens privately owned by households living in four use case cities of the Nature4Cities project: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). A water balance model is built to incorporate rainfall to soil dynamics in the model (see Sect. 5.2.1.1).

The modeling approach we adopt is based on the concept of causal chain layering, where a sequence of events that are assumed to have a causal relationship are modeled, leading to a particular outcome (in our case changes in the make-up of private gardens affecting water balances). The relationships are drawn from both

social-psychological perspectives and elements of social practice theory. We focus on factors by which a transformation can take place and affect a larger share of NBS-based gardens for water management on private property. The type of NBS is not specified in the absence of specific water balance impacts data, but generalized into green gardens, partially green gardens, and paved gardens. The adoption or absence of green gardens over time, based on different potential policy instruments by the municipality and other stakeholders is examined. Three instruments are assessed: (i) a subsidy that affects financial incentives, (ii) the organization of gardening workshops facilitated by the municipality, and (iii) the establishment of gardening networks including garden space provisioning, garden sharing, and knowledge exchange.

5.2.1 Model Setup: Change in Garden Type

The model simulates agent decisions to change their gardens based on the *motivation*, *ability to change*, and *willingness to change* concepts, as formerly introduced in Sect. 5.1. These pillars are used to derive a probability by which change happens, which varies depending on segments of the population as defined by motivation and ability to change. The framework is depicted in Fig. 5.1.

5.2.1.1 Simulation of Garden Change Behavior

The simulation is limited to agents that own gardens and starts with the identification of the baseline situation for their private gardens, distinguishing among the following options (based on their land use type): (a) fully paved gardens, (b) partially green gardens (50% surface area), or (c) fully green gardens (100% surface area).

The change in a person's garden is not a trivial and fast decision. As such, it is not implemented in the simulation as a binary 0/1 switch. Instead, each agent will have a bar measuring the "effort made to make a change" in the simulation, which goes from 0 to 100%, and only once 100% is reached a garden is transformed. This allows simulating the presence of inertia in such an important decision. A step toward the 100% is simulated depending on a successful probability exceedance roll that is carried out per time step (in the simulation set to 3 months). Such a roll establishes an instantiation of the *probability of change* for an agent. If the draw is below 0.9 (90%) no "change step" occurs, but if it is 0.9 or higher a "change step" occurs in the simulation, adding a set percentage increase to the change bar.

The *probability of change* is formed by the linkage between motivations, ability to change, and willingness to change segments, described below. All qualitative elements are thereby combined to represent a likelihood (between 0 and 1) by which a change will happen.

Fig. 5.1 Relational model used to build the simulation

To set heterogeneity in the simulation, the increase in the “effort to make a change” bar is further varied between two types of agents called “transformative decision” and “incremental decision” agents. An *incremental decision agent* needs four successful probability exceedance rolls ($4 \times 25\%$) to change their garden, while a *transformative agent* needs two successful probability rolls ($2 \times 25\%$) to enact the change. The rationale behind the transformative vs. incremental setting is that some people will make changes in their lives swiftly, while others gradually, with large variations between people on the pace of change.

Thereby, multiple steps are required before the 100% value is reached, indicating successive efforts required before a garden change occurs. Such efforts can also partially vanish in the simulation, representing the idea that plans for making change can be deprioritized or cancelled as other events happen in life. This “decay” or “erosion” is simulated with a decline in the “effort made to make a change” bar, which can occur every 3 months and can be varied.

The additional rationale for introducing the process of “decay” or “erosion” is also that if the simulation is run for a very long time span, say 1000+ years, it will not lead to all gardens becoming green. This is because without such a “decay rate” all gardens would become green, given enough time at positive probabilities of change, even at very low levels, unless these probabilities are zero. This is deemed unrealistic, since even with large scale support not all people will want to have a green garden.

Each agent is initialized with motivational characteristics, which define their motivation to create change. In the simulation, these motivations are related to the following environmental, financial and social aspects:

- M1—Environmental values, that is, those responding to the question: What is my attitude toward nature?
- M2—Financial values, that is, those that determine whether or not I am financially motivated when greening my garden.
- M3—Social preference, that is, the answer to the question: Do you consider gardening a pleasure?
- M4—Social network, expressed by the answer to the question: Are my friends interested in gardening?

The motivational characteristics are set based on theoretical reasoning informed by the literature, and not informed by detailed surveys, as this was outside of the scope of the study. The descriptions below should therefore not be interpreted as real-life characterizations. The agents in the simulation are categorized into two groups that identify the variety in their motivation and abilities. “Proud Gardeners” forming a group of people who see gardening as a favorable past-time and “Backyard Barbeques” who favor using gardens for barbequing and family purposes. In reality, more groups can likely be identified in relation to household typologies (e.g., single person, multiple people, and families). The motivational characteristic influences the agents using the Likert scale from 1 to 5 (indicating very low to very high motivation) presented in Table 5.1.

For example, for the question “what is my attitude toward nature?” a value of 1 means that the agent gives a very low importance to the natural environment, and vice versa for a ranking of 5. To simplify the simulation, it is assumed that motivations are fixed, except for the influence of the municipality interventions that the user can set: a subsidy that affects financial incentives, the organization of gardening workshops facilitated by the municipality, and the establishment of gardening networks including garden space provisioning, garden sharing, and knowledge

Table 5.1 Motivation and Ability Likert scale rating for segments in the simulation

Segments	Motivations				Abilities			
	M1	M2	M3	M4	A1	A2	A3	A4
Proud gardeners	5	1	3	1	2	4	2	3
Backyard barbeques	1	2	1	1	3	3	1	3

exchange. Each of these interventions' forms enabling conditions that either affect motivational factors or ability to change factors or both, as follows:

- Organization of garden workshops: when the agent is connected to a garden workshop influencer, this increases the A3 knowledge available by 2, up to a maximum of 5.
- Establishment of gardening networks: when the agent is connected to a garden networking influencer, this increases the score for motivation M4 related to social network to 5.
- Gardening subsidies: improves the score for ability finances available to 5 and increases the score for motivation A1-finances-available by 1, up to a maximum of 5.

The model could be extended to further address changes in motivation. For example, "are my friends interested in gardening?" will change depending on the friendships of the agent with other agents and the gardens that these agents own, and this can affect the social network motivation of the agent. Such changes are informed by enabling conditions and barriers that form an agent's local context. In this case, an enabling condition is the type of gardens that friends have, which informs on whether friends are interested in gardening.

Each agent is also initialized with characteristics that sum up their ability to change, in terms of what (physically, socially, economically, external to their mental perceptions) will help them in the process of change. In the simulation, this relates to the following financial, timing, knowledge, and resource abilities:

- A1: Do I have the finances available to change my garden?
- A2: Do I have the time available in my schedule to change my garden?
- A3: Do I have the knowledge or is there knowledge support in my network to change my garden?
- A4: Is there a garden center nearby where I can obtain the items needed for my garden's change?

Each agent always has a ranking for an ability to change on a Likert scale, similar to motivation, from 1 to 5 (indicating very low to very high ability) (see Table 5.1). In reality, abilities to change are never fixed but always vary depending on the agent's circumstances as simulated (such as for time available), friends' network with levels of gardening knowledge, and the existence of garden centers. To simplify this, however, aspects in the simulation will be fixed as otherwise each individual ability will need to be simulated (such as income level variation), and this is not the purpose of our model.

An agent is part of a population segment that defines their willingness to change that is expressed as a probability for being driven by a certain purpose. Before expressing this, a qualitative description of the segment is made, as informed by the three aspects:

- People in a segment will either carry out change rapidly (called transformative), or carry out the change slowly (called incremental) as defined above.

- A segment is assumed homogenous in how important particular motivations are.
- A segment is assumed homogenous in how they score on particular abilities to change.

An example of a dummy segment is an “Incremental Pioneering Gardener,” which is described as a person who “cares substantially about nature, is willing to take incremental steps to change his/her garden if he/she has time available and will fit the garden to what means are available to him/her; he/she is thus not reliant on financial resources, considers gardening a pleasure, and the social influence of friends does not matter substantially.”

In terms of motivation this hypothetical segment ranks high (value 4) on attitude toward nature, very high on the absence of financial motivation when greening the garden (value 5), high (value 4) on considering gardening a pleasure, and finally the interest of friends in gardening is not an important motivation (no ranking).

In terms of ability to change, this segment is typically initialized based on a low ranking (value 2) for financial resources available, a high ranking (value 4) for time available, a ranking of 5 for knowledge/support available (very high), and a medium ranking (value 3) for a garden center nearby. The rationale for such initializations relates to different segments. In the simulation, this will be done by a normalized initial distribution of the preferences, with the mean being the typical ranking. A dummy logic fitting the dummy example above could be that pioneering gardeners are likely younger people that are environmentally conscious and as such live in areas where gardening resources are available. The willingness to change of this type of people is thus defined by the combination of their motivational attitude toward nature and pleasure in gardening, and their ability is usually underlined by seeking out conditions to have the ability to fulfill these motivations.

5.2.1.2 Transformation to Probability of Change per Segment

A single value of the probability of change (P^c) is formulated for each segment. This is done starting from separate probabilities for motivation P^M and ability P^a and multiplying these:

$$P^c = P^M \cdot P^a, \quad 0 < P^c, P^M, P^a < 1 \quad (5.1)$$

The probability values are multiplied such that all probabilities fall between 0 and 1. The probabilities are set based on a sigmoid function that relates to the Likert score (L), which ranges between 0 and 1. A sigmoid function is often used to represent a growth process. The standard logistics function (a version of the sigmoid function) is chosen here for its simplicity, ease of interpretation, and proven applicability for statistical analysis:

$$P = \frac{1}{1 + e^{-(\beta_0 + \beta_1 L)}} \quad (5.2)$$

Fig. 5.2 Motivation probability curve example (left) and ability probability curve example (right)

The selection of the parameters β_0 and β_1 defines the result of the Likert ranking translation into a probability value.

In the case of motivation, the function given by Eq. (5.2) is utilized as is. It is also assumed that motivation probabilities are multiplicative, such that if all motivations are high, the probabilities are high, and if one motivation is very low, the probability will drop significantly, thus forming a constraint. In other words, different motivations influence each other, and having just a single very high motivation is insufficient for change. Choosing $\beta_0 = -3$ and $\beta_1 = 1.3$ we obtained the probability curve for motivation shown in Fig. 5.2 (left).

The joint motivational probability for the “Incremental Pioneering Gardener” using these parameters would then be:

$$P^M = 0.9 * 0.97 * 0.9 = 0.786 \quad (5.3)$$

In case of ability to change, we used an adjusted version of Eq. (5.2), based on the idea that abilities to change are not multiplicative, but additive. One can score low on one ability to change but this does not affect other abilities to change. As such, in order to make the total joint probability of the ability to change sum to one, an adjustment factor is needed, based on the number of ability factors f that are summed. The adjusted function becomes:

$$P = \frac{1/f}{1 + e^{-(\beta_0 + \beta_1 L)}} \quad (5.4)$$

If we choose $\beta_0 = -7$ and $\beta_1 = 2.5$ we obtain the probability curve for motivation shown in Fig. 5.3 (right).

The joint motivational plus ability probability for the “Incremental Pioneering Gardener” would then be:

$$P^a = 0.03 + 0.238 + 0.03 + 0.03 = 0.328 \quad (5.5)$$

Fig. 5.3 Percentage variations in the numbers of each type of garden between the beginning and the end of the simulations in each of the four cities

The final joint probability obtained by Eq. (5.1) for this example would be:

$$P^c = 0.787 \cdot 0.328 = 0.25 \quad (5.6)$$

Therefore, for this segment, based on the conditions set in the example, there is a 25% chance to make a stepwise effort of change in the change bar. Given that four steps are required to reach 100% and a probability check is done four times per year (once every 3 months), ignoring “effort decay,” on average the “Incremental Pioneering Gardener” will change their garden within a 1 to 2 years’ time, assuming a stable motivation and a stable ability to change.

The importance of motivation becomes clear if we adjust the values to show how low motivations influence the outcomes. If the interest of friends in gardening was important and the scoring here was very low, the motivation probability outcome would translate into:

$$P^M = 0.9 \cdot 0.97 \cdot 0.9 \cdot 0.154 = 0.122 \quad (5.7)$$

The joint probability would then change to:

$$P^c = 0.122 \cdot 0.328 = 0.040 \quad (5.8)$$

This would mean that for this segment there is a 4% chance to make a stepwise effort of change in the change bar. Given that four steps are required to reach 100% and a probability check is done four times per year (ignoring “effort decay”), this implies that this agent segment would change their garden within 6–7 years; unless a growing number of friends become interested in gardening and motivate the agent to change their garden, thereby improving the motivational score for the “social network” motivational factor.

5.2.2 Model Setup: Water Balance Model

A key purpose of the simulation is understanding the impact that private gardens without and with NBS can have on water management across the city. To this end, a water balance model was introduced in the simulation to assess how different types of private gardens affect the soil water balance and water run-off following rainfall events, as an indicator for potential flooding.

The water balance simulation is linked with the change in garden type by taking into account the type of garden, including paved gardens, partially paved/green gardens, and green gardens. For each of these garden types, different parameter values are introduced due to which soil moisture content and runoff vary. As such, a picture for individual gardens and the entire city emerges over time as rainfall affects runoff and soil moisture over time, along with changes in garden types.

The soil water balance model takes into account four processes: rainfall, plant transpiration, soil evaporation, and net runoff. For the sake of simplicity, water transfer processes between soil layers, including percolation and lateral water exchanges, were not considered. The main water balance equation used was taken from (Sheikh, 2006; Sheikh, Visser, & Stroosnijder, 2009):

$$\Delta s_t = \frac{P_t - R_t - E_t - T_t}{d * 1000} \quad (5.9)$$

where Δs_t is the change in soil moisture (in m^3 per soil layer volume in m^3), d is the depth of the soil layer in meters, P_t is precipitation rate in mm, R_t is net runoff in mm, E_t is evaporation in mm, and T_t is transpiration in mm. The factor 1000 at the denominator is used to convert from 1 mm to 1 meter, in order to translate to a m^3 of water per m^2 of soil surface area (being 1 mm of rainfall equivalent to 1 liter of water per m^2). Thereby the water content in the soil s_t changes every time step as:

$$s_{t+1} = s_t + \Delta s_t \quad (5.10)$$

Precipitation was incorporated as an exogenous variable using daily rainfall data from 2007 to 2017 taken from the European Climate Assessment Dataset project (<https://www.ecad.eu/>). Runoff was simulated based on the SCS Curve Number Procedure developed in the US (Neitsch, Arnold, Kiniry, & Williams, 2011), which was also adopted by (Sheikh et al., 2009). The value calculates the runoff in mm based on the amount that is “abstracted” before it reaches the soil (in plants, puddles) and the amount that is “retained” by the soil. The general equation is:

$$R_t = \frac{(P_t - I_t)^2}{(P_t - I_t + S_t)} \quad (5.11)$$

where I_t is the abstraction of precipitation P_t before it reaches the soil as a combined variable for surface storage (puddles), interception by plants, and root infiltration, and S_t is the retention of precipitation water in the soil. Thereby, the higher the

soil retention of precipitation and the abstraction of precipitation, the lower the runoff, inclusive of interaction between these elements. To simplify the equations, the value of I_t is typically assumed to be 0.2 times the soil retention, resulting in the following equation:

$$R_t = \frac{(P_t - 0.2S_t)^2}{(P_t + 0.8S_t)} \quad (5.12)$$

The values of soil retention are calculated from so-called curve number (CN) values, which indicate the share of imperviousness of an area, based on a parameterized equation (Sheikh, 2006; Sheikh et al., 2009):

$$S_t = 25.4 \left(\frac{100}{CN} - 1 \right) \quad (5.13)$$

The values for the CN or share of imperviousness are described in (Neitsch et al., 2011) varying by hydrological soil group (A: sandy soils, B: loam soils, C: sandy clay loam soils, D: clay soils) and type of land use (agricultural lands and urban areas). The values used in our simulation are 98 for paved gardens (based on being nearly impervious), 75 for partially green gardens (being somewhat permeable), and 50 for green gardens (indicating a permeable soil). Soil evaporation is calculated based on the calibrated crop water balance model in (Tribouillois et al., 2018), based on 7 years of observation of evapotranspiration for several different soil covers. The empirical equation is based on first calculating the total potential evapotranspiration (PET), and subsequently adjusting this with crop specific coverage, soil water content, and capacity impacts. The equation was adopted as:

$$E_t = PET_t \cdot \left(1 - \frac{k}{k_{max}} \right) \cdot \left(\frac{S_t}{S_{max}} \cdot E_{min} + 1 - E_{min} \right)^b \quad (5.14)$$

Where PET_t is the potential evapotranspiration (PET) of the soil layer which is first adjusted by the crop foliage. This is done by the coefficient k , which is a crop- or foliage-specific evaporation coefficient divided by k_{max} , a boundary parameter such that there is no evaporation if k equals k_{max} . Subsequently, potential evapotranspiration is adjusted by the soil water situation, where S_t is the soil moisture content. The closer the soil moisture content to the maximum soil moisture S_{max} , the higher the evaporation. The adjustment parameter E_{min} is introduced as a minimum evaporation rate that varies per soil type, regardless of soil moisture content. Finally, the soil water situation component is adjusted by a power factor parameter b which is empirically estimated, and was introduced to add a weighting on the soil moisture effect versus the crop effect in the equation.

Several calculations for PET are possible, of which the ‘‘Thorntwaite formula’’ approach was used because of its parsimoniousness (Thornwaite, 1948) and validity in providing a reasonable approximation of PET (Pereira & Paes De Camargo, 1989) based solely on daily and monthly temperature values for a location. The formula is empirically established as follows:

$$PET_t = 1.6 \cdot \left(\frac{10 \cdot T_t}{I} \right)^e \quad (5.15)$$

where I is a heat index that captures the relative warmth for the location across the year, T_t is the daily temperature in Celsius degrees, and e is an empirically fitted parameter that adjusts the result based on the heat index. The heat index is calculated as:

$$I = \sum_{m=1}^{12} \left(\frac{T_m}{5} \right)^{1.514} \quad (5.16)$$

where T_m is the mean monthly temperature.

The value of the parameter e can be calculated using the polynomial:

$$e = (6.75 \cdot 10^{-7}) I^3 - (7.71 \cdot 10^{-5}) I^2 + (1.792 \cdot 10^{-2}) I + 0.49239 \quad (5.17)$$

The calculation of transpiration, T_t , is based on the DREAM model (Distributed model for Runoff Evapotranspiration, and antecedent Soil Moisture Simulation) described in (Manfreda, Fiorentino, & Iacobellis, 2005). The model utilizes the potential evapotranspiration (PET) that is adjusted with soil moisture content and a canopy fraction-specific parameter. The equation is formulated as:

$$T_t = m \cdot \min \left(1, \frac{1}{3} \frac{S_t}{S_{\max}} \right) \cdot PET_t \quad (5.18)$$

where, similarly to Eq. (5.12), the potential evapotranspiration PET_t is adjusted by the soil water situation. S_t is the soil moisture content; the closer it is to the maximum soil moisture $S_{\max}$, the higher the evaporation. Subsequently, the resulting value is adjusted by a canopy specific parameter value m (fraction of soil covered by vegetation). The value has been estimated as 0.35 for grass, 0.45 for crops, and 0.5–0.77 for trees. In our simulation, a value of 0 was chosen for paved gardens, a value of 0.25 for partially open gardens, and a value of 0.5 for open gardens, assuming an urban setting with limited coverage.

5.3 Model Results

The simulation provides two key outputs. First, changes in the number of gardens based on paved, partially green, and green NBS-based garden types. Second, the runoff across the city at a cumulative level based on local rainfall patterns and soil types associated with the garden types.

Each of the three models was run for four use case cities: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). The spatial and population data for the case studies are more extensively described in (Nature4Cities, 2019). The models were run with the same

input data variations. Twelve model runs were established for each city, based on variation in two population segments with either 100% of the population allocated as “Proud Gardeners” or 100% of the population allocated as “Backyard Barbeques.” Furthermore, variation was added for each of these two groups. Firstly, the results were simulated twice for both groups with no interventions. Subsequently, four interventions’ combinations were simulated for each group: (1) only 80 municipal agents organizing gardening workshop; (2) only 100 gardening municipal agents organizers’ network groups; (3) only 1000 annual financial subsidies per year for garden transformation; and (4) a combination of all three interventions occurring at the same time.

A summary of the results for the case studies is reported in Fig. 5.3, which shows the percentage variation of the number of each type of gardens in each city, between the beginning and the end of the simulation, distinguishing the two population agents. The values for each population are calculated as the average of the simulation runs. One can observe relevant percentage increases in the number of green gardens and decrease in the number of paved gardens among the members of the 100% “Proud gardeners” community. As expectable, much more modest increases in the numbers of green gardens are observed among the agents belonging to the community of 100% “Backyard Barbeques.” Çankaya is the city with the lowest increases of green garden in both communities.

In the following sections, the results for each simulated city are described in more detail.

5.3.1 *Szeged Case Study*

The simulation area was selected to cover the center of Szeged with surrounding areas and satellite peri-urban areas.

The simulation shows a substantial difference between the “Proud Gardeners” and “Backyard Barbeques” segments in terms of transitions from paved to NBS-based green gardens, due to differences in gardening-related motivation and ability between these segments. In both cases, at the start of the simulation, the number of paved gardens ranges from about 350 to 380. In case of “Proud Gardeners,” 120 to 150 paved gardens are transformed into partially green and green NBS-based gardens, whereas in case of “Backyard Barbeques” only about 30 paved gardens are transformed. In addition, the majority of transformed gardens become green NBS-based gardens for “Proud Gardeners,” whereas the majority of transformed gardens for “Backyard Barbeques” become partially green gardens (see Table 5.2).

The effect of gardening knowledge workshops and gardening network group organizers, and subsidies as individual measures, is nonexistent for “Backyard Barbeques.” In case of “Proud Gardeners,” the effect is nonexistent for gardening knowledge influencers, small for gardening group organizers, with 35 more transformed paved to green gardens over the modeled period, and large for subsidies with close to 130 additional gardens transformed from paved to green gardens (see

Table 5.2 Szeged simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m ³)	Cumulative runoff final year (m ³)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	354	216	165	207	119	215	253,300,000	25,725,000
2	100% proud gardeners	0	0	0	383	230	184	243	91	185	259,000,000	26,220,000
3	100% backyard barbeques	0	0	0	380	353	162	181	104	112	265,200,000	27,860,000
4	100% backyard barbeques	0	0	0	359	338	174	187	104	112	265,110,000	27,943,000
5	100% proud gardeners	80	0	0	367	219	172	200	92	212	243,900,000	24,567,000
6	100% proud gardeners	0	100	0	367	188	168	193	91	245	248,770,000	25,100,900
7	100% proud gardeners	0	0	1000	385	94	178	65	97	501	245,500,000	24,769,000
8	100% proud gardeners	80	100	1000	367	47	170	53	94	531	226,900,000	22,750,000
9	100% backyard barbeques	80	0	0	368	346	155	161	106	122	270,000,000	28,460,000
10	100% backyard barbeques	0	100	0	405	369	150	168	108	126	273,000,000	28,630,000
11	100% backyard barbeques	0	0	1000	388	365	173	184	91	103	269,200,000	28,310,000
12	100% backyard barbeques	80	100	1000	366	304	198	198	97	159	267,090,000	27,810,000

Table 5.2). Interestingly, in case of combined interventions, there is a medium-sized effect on “Backyard Barbeques,” with an additional 50 gardens transformed from paved to green, demonstrating that combining measures can be more effective for particular segments than others.

The garden transformation has a non-measurable impact on total private garden water runoff for “Backyard Barbeques” segment model runs. In case of “Proud Gardeners,” the growth in green NBS-based gardens reduces water runoff by over 10% in the case where close to 300 paved gardens are transformed into partially green and green gardens. The estimated order of magnitude is thereby 5–10% of the water runoff that can be reduced by private garden-based NBS promotion.

5.3.2 *Alcalá de Henares Case Study*

The simulation area was selected to include the city center of Alcalá de Henares with surrounding areas and satellite peri-urban areas. The whole area includes the edible forest NBS use case proposed as a green space in the Nature4Cities project (Nature4Cities, 2019). The simulation shows limited changes for “Backyard Barbeque” segments and substantial changes for “Proud Gardeners” in terms of transitions from paved to NBS-based green gardens, due to differences in gardening-related motivation and ability between these segments. At the start of the simulation, the number of paved gardens range between 670 and 800. In case of “Proud Gardeners,” 240 to 300 paved gardens are transformed into partially green and green NBS-based gardens, whereas in case of “Backyard Barbeques” only about 30 to 40 paved gardens are transformed. In addition, about half of transformed gardens become green NBS-based gardens for “Proud Gardeners” and the other half partially green gardens. The majority of transformed gardens for “Backyard Barbeques” become partially green gardens (see Table 5.3).

5.3.3 *Metropolitan City of Milan Case Study*

The simulation area was based on a portion of the North of the Milan Metropolitan Area centered on the quarry restoration site in Parco Lago Nord (about 15 km north of Milan city center) selected with surrounding neighborhoods.

The simulation shows a transformation of about 80 to 90 paved gardens into partially green and green gardens for “Backyard Barbeques” segment, relative to a transformation of close to 500 paved gardens into both partially green and green gardens for “Proud Gardeners.” In both cases at the start of the simulation, the number of paved gardens ranges from 1350 to 1400 (see Table 5.4).

The influence of gardening knowledge workshops, gardening network group organizers, and subsidies does not lead to additionally transformed gardens for “Backyard Barbeques,” showing the lack of influence of additional motivational and ability factors. In case of “Proud Gardeners,” the effect is not measurable for

Table 5.3 Alcalá de Henares simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m³)	Cumulative runoff final year (m³)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	801	516	211	337	177	336	122,443,876	13,157,346
2	100% proud gardeners	0	0	0	709	461	222	334	223	359	126,219,000	13,724,784
3	100% backyard barbeques	0	0	0	673	632	205	236	198	208	131,859,470	15,318,105
4	100% backyard barbeques	0	0	0	709	679	230	249	223	234	139,723,138	16,319,339
5	100% proud gardeners	80	0	0	694	413	223	327	146	323	117,229,700	12,578,218
6	100% proud gardeners	0	100	0	756	465	217	321	224	411	128,962,056	13,916,964
7	100% proud gardeners	0	0	1000	672	135	233	118	238	890	112,762,481	12,364,437
8	100% proud gardeners	80	100	1000	668	141	223	94	175	831	100,678,370	11,151,138
9	100% backyard barbeques	80	0	0	719	685	246	265	175	190	135,234,450	15,678,575
10	100% backyard barbeques	0	100	0	771	734	225	246	191	207	136,389,930	15,857,002
11	100% backyard barbeques	0	0	1000	690	654	205	226	210	225	136,660,000	15,921,648
12	100% backyard barbeques	80	100	1000	726	654	249	288	226	258	136,421,300	15,609,300

Table 5.4 Metropolitan city of Milan simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m³)	Cumulative runoff final year (m³)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	1373	874	502	711	373	663	1,153,782,700	118,912,091
2	100% proud gardeners	0	0	0	1390	917	488	656	385	690	1,191,479,000	122,381,000
3	100% backyard barbeques	0	0	0	1404	1322	463	502	380	423	1,217,212,257	128,300,480
4	100% backyard barbeques	0	0	0	1410	1334	491	540	396	423	1,206,933,500	127,273,740
5	100% proud gardeners	80	0	0	1356	828	448	653	373	696	1,167,484,600	119,423,008
6	100% proud gardeners	0	100	0	1344	887	514	665	401	707	1,155,100,000	118,499,250
7	100% proud gardeners	0	0	1000	1405	393	459	262	355	1564	1,122,606,470	113,974,702
8	100% proud gardeners	80	100	1000	1355	300	490	268	403	1680	1,119,285,721	113,404,603
9	100% backyard barbeques	80	0	0	1355	1299	503	520	368	407	1,201,793,500	126,945,900
10	100% backyard barbeques	0	100	0	1312	1251	491	531	376	397	1,204,644,599	127,176,382
11	100% backyard barbeques	0	0	1000	1371	1293	508	560	364	390	1,246,314,209	131,399,937
12	100% backyard barbeques	80	100	1000	1393	1290	495	552	388	434	1,210,696,790	127,365,850

gardening knowledge influencers and small for gardening group organizers, and large for subsidies with close to 500 additional gardens transformed from paved to green gardens (see Table 5.4). Interestingly, in case of combined interventions there is a medium-sized effect on “Proud Gardeners” with an additional 100 gardens transformed from paved to green versus only providing subsidies, showing that combining measures can lead to better results.

The garden transformation has a non-measurable impact on total private garden water runoff for “Backyard Barbeques” segment model runs as there is a limited transformation from paved to green gardens. In case of “Proud Gardeners,” the growth in green NBS-based gardens reduces water runoff by about 5% in the case where close to 1000 paved gardens are transformed into partially green and green gardens. The order of magnitude as estimated is thereby up to 5% of water runoff that can be reduced by private garden-based NBS promotion.

5.3.4 Çankaya Municipality Case Study

The simulation area was based on the southeast portion of Ankara where Çankaya municipality is located. The simulation shows a substantial difference between the “Proud Gardeners” and “Backyard Barbeques” segments in terms of transitions from paved to NBS-based green gardens, due to differences in gardening-related motivation and ability between these segments. The number of paved gardens at the start of the simulation ranges from 190 to 270, while the number of initial partially green gardens ranges from 160 to 220, and the number of NBS green gardens from 700 to 800. Thereby the households in the municipality already have mostly green gardens as opposed to paved gardens. During the simulations, in case of “Proud Gardeners,” close to 70÷100 paved gardens are transformed into green NBS-based gardens. In case of “Backyard Barbeques” segments, only about 15 paved gardens are transformed. Of the transformed gardens, nearly all become green NBS-based gardens for “Proud Gardeners” (see Table 5.5).

5.4 Limitations of the Model

Some simplifications and assumptions were necessary to make the model operational using the information available. Firstly, a number of assumptions were necessary when local data were not available (e.g., on exact number and location of gardens, soil type) and conducting local surveys for these particular model parameters was not possible in the context of this work. Secondly, given the absence of specific data for particular buildings or built areas, generalized assumptions based on land use data were made. If more spatially explicit and survey-based data had been available, deeper and more location-specific insights could have been gained. For example, data on the actual instead of inferred type of garden privately owned

Table 5.5 Çankaya municipality simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set		# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m ³)	Cumulative runoff final year (m ³)
					Start	End	Start	End	Start	End		
1	Household mix gardeners	0	0	0	241	147	159	147	787	893	278,875,680	28,806,589
2	100% proud gardeners	0	0	0	198	125	170	167	787	863	282,621,000	29,182,840
3	100% backyard barbeques	0	0	0	233	218	201	208	752	760	293,545,000	30,865,200
4	100% backyard barbeques	0	0	0	234	226	181	177	796	808	294,414,000	31,043,860
5	100% proud gardeners	80	0	0	213	135	173	160	751	842	279,634,000	28,922,090
6	100% proud gardeners	0	100	0	258	179	187	176	795	885	287,024,000	29,654,200
7	100% proud gardeners	0	0	1000	225	57	179	64	795	1078	270,198,000	27,816,820
8	100% proud gardeners	80	100	1000	252	49	163	58	792	1100	271,416,800	27,963,900
9	100% backyard barbeques	80	0	0	255	244	197	195	765	778	297,173,290	31,319,940
10	100% backyard barbeques	0	100	0	249	229	216	221	761	776	294,381,057	30,916,457
11	100% backyard barbeques	0	0	1000	270	259	171	173	718	727	297,249,331	31,278,000
12	100% backyard barbeques	80	100	1000	193	179	158	150	791	813	294,819,370	31,039,300

by citizens could allow a more accurate assessment of the potential for rainwater management through NBS transformation of paved gardens. As such, in case of further developing the existing models for purposes of supporting decision making on NBS development, a data collection exercise would need to be programmed to combine local surveys with observational data.

In the applied ABM, generic garden types are chosen to make the model parsimonious for displays purposes, in order to establish a valid relationship between private garden transitions and city water management. NBS-specific water management data would be required for a real-world usable model, ideally tailored to different soil types on which the NBS are placed within an urban context. Similarly, to assess the transition from one garden type to another, the population is segmented with different start values for motivation and abilities. In a real world usable model, these segments would need to be investigated based on location-specific statistical survey work, inclusive of motivational and ability-related questions from which different segments can be deduced, for example, through exploratory data analysis (EDA) or cluster analysis (CA). To make the model more concretely usable, historical patterns of garden change and the causes of change would need to be studied in more detail, so as to provide boundary conditions on how these changes occur, for example, distinguishing the real cases of event-based changes, such as when moving to a new house, or changes happening on an on-going basis, or both. In the present model, the possibility of a garden type change occurring is set to be *in itinere*, with decision moments happening on a weekly basis. A further limitation lays in the fact that the effect of the interventions has not been evaluated with real world data related to the situation with no interventions. In the model, three interventions are currently available as inputs, setting the number of subsidies, the number of influencer agents that organize local gardening workshops, and influencer agents that facilitate the setup of gardening networks. Finally, the tool used for developing the showcase models, that is, Netlogo, was found to be highly suitable for rapid model development and testing of the conceptual ideas. In fact, Netlogo allows quick adjustments, and provides a visual interface with no additional coding required to obtain results in a versatile manner including spatial maps. However, the main limitation was found in two aspects. Firstly, the limited ability of the platform to carry out many simulations in a sequential and automated manner, as opposed to having to manually log the results of every run, and start every new run manually. Secondly, the limited ability of the platform to link with web and data streaming architecture, which is possible in case of other ABM packages such as MESA (<https://mesa.readthedocs.io/en/master/>), MASON (<https://cs.gmu.edu/~eclab/projects/mason/>) and Repast-Simphony (<https://repast.github.io/index.html>) as these utilize cross-platform programming languages including Java and Python, that can be readily linked to web and data platform architecture. When developing such models for replicability purposes within simulation platforms for recurring use, one of these different platforms would thereby be selected for programming. The downside is that these languages have more complexity and do not come with similar in-built visualization automation, thereby requiring substantially more coding time to provide a working model.

Based on the assumption simplifications listed above, the results cannot be interpreted on an absolute basis of the number of gardens transformed to green NBS-based garden, or on the absolute size of run-off in cubic meters of water. In other words, the results cannot be taken as a direct transition pathway, where the interventions can be used to evaluate the impact a municipality has on the number of private gardens in the city. Instead, the values should be interpreted on a comparative basis between model runs, where changes and the different speed of changes occurrences can suggest whether one solution is better than another.

The results inform whether this type of assessment modeling can be useful from a planning perspective, especially in terms of providing insights in the ways municipal incentives could assist with the greening of private gardens for NBS promotion in order to address potential city water management issues.

5.5 Conclusions and Recommendations for Future NBS Agent-Based Modeling Assessments

The purpose of this work is gaining an improved understanding of the extent to which substantial rainfall in short periods can be mitigated by increasing the number of green private gardens in a city. Within this context, the model allows to assess how “soft” (garden networks and gardening workshops) and “hard” (monetary) incentives can help to further the adoption of NBS on private property. Several scenarios were tested to create a tool to empower further discussions on the approaches that could be implemented in order to improve the success for NBS adoption by households through facilitation at a municipal level.

The ABM approach was applied to the cases of four different towns in Europe: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). The simulation results demonstrated that changing the make-up of private gardens could have up to a 20% impact on water run-off and catchment in cities with mostly paved gardens and large private garden areas, but that the typical impact of such changes is in the order of 5–10%. However, these results are not representative for peak flows that may result in flash floods.

In the simulation, two different opposing segments of the population were simulated: “Proud Gardeners” and “Backyard Barbeques.” The former with high motivation on environmental values and social preferences, high ability in time but lower in finances, and the latter with low motivation for gardening on all motivational factors, but with higher financial means. A substantial variation between the two different segments emerged, primarily due to the low motivations of the “Backyard Barbeques” segment. While very few (5%) “Backyard Barbeques” activated garden transformations in the base case scenarios, in the case of “Proud Gardeners” up to 40% of paved gardens were transformed into fully green NBS gardens.

The simulations also highlighted how different qualitative and quantitative policy and social programs that could be setup by a municipality can be simulated, in

terms of their potential impact on people's socioeconomic factors, such as motivation and the ability to implement green NBS gardens. Three types of such interventions were simulated: (i) organization of garden workshops that increases knowledge available, (ii) establishment of gardening networks that increased motivation, and (iii) gardening subsidies that increased finances available as an ability. The simulations established that based on the loadings that were included, limited improvements were established due to garden workshops and gardening networks, but that making gardening subsidies available had a significant impact in the order of an additional 20–40% of gardens transformed from paved to green gardens. The results also showed that combinations of interventions could have an impact even if individual interventions do not, because they can lift multiple barriers. The reason is that it is assumed that motivational factors relate to probabilities that are multiplicative, such that when increasing motivation for multiple factors, the overall probability of transforming a garden grows. In other words, if there is more environmental motivation and social motivation, the combined effect is greater than the effect of these motivations alone. The results indicate that by using such simulations to evaluate actual segments based on local surveys, insights can be gained into how combined facilitation of NBS changes can work best together.

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