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Urban garden as a water reservoir in an urban area – a literature review

Keywords: meta-analysis, water retention indicators, community garden, soil maintenance, planting type

Introduction

In the 21st century, cities have become a place where the percentage of the world's population has become higher than that of non-urban areas. Thus, today cities have become the places where a sustainable living environment is more relevant (Brown, Keath & Wong, 2009). According to the United Nations projections, the world's population will continue to grow to around 8.5 billion in 2030 (United Nations Department of Economic and Social Affairs, Population Division [UN DESA], 2022), and two-thirds of the human population will already live in cities in 2025 (Russo, Escobedo, Cirella & Zerbe, 2017), of which 8 million will be in Europe and as many as 920 million in Asia (UN DESA, 2022). With traffic migration from rural to urban areas, there is a growing need for water conservation in the cities. Against the backdrop of the climate crisis, planners are

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trying to prepare a resilient environment by ensuring proper water management in urban spaces (Brown et al., 2009). According to Goal 6 of the SDGs, 25% of the population will be affected by drought and steppe formation in 2050. Therefore, researchers have called for actions related to infrastructure investments aimed at the protection and restoration of aquatic ecosystems, the improvement of water quality through the reduction of pollution, water efficiency through its efficient use, integrated resource management and the public participation of urban communities in the above actions (Barcena, Cimoli & Perez, 2018). One solution to this issue is the creation of green infrastructure that can act as a buffer zone in the city by using urban gardens for climate regulation, carbon capture, food security, educational opportunities on environmental issues and water retention (United States Environmental Protection Agency [US EPA], 2021; Tomatis, Egerer, Correa-Guimaraes & Navas-Gracia, 2023).

Urban gardening is defined as crops and livestock production in cities (Tomatis et al., 2023), but different scales of urban gardening must be considered. In Europe and Asia, these activities take many forms, such as allotment gardens, urban farms, community orchards (Lin, Philpott & Jha, 2015; Burchard-Dziubińska, 2020), community gardens (Lin et al., 2015; Burchard-Dziubińska, 2020; Menconi, Heland & Grohmann, 2020; Kingsley et al., 2021). The definition of the ‘urban garden’ (UG) thus includes many different forms of cultivation and land use, using nature-based solutions (Cabral, Costa, Weiland & Bonn, 2017). City gardens are variable in time and space, and they are easy to adapt and transform for the needs of specific groups of residents and environmental purposes. Governance by formal or neighborhood groups is easily supported by public institutions and local authorities (Menconi et al., 2020).

Asia’s population quadrupled in the 20th century (Akaeze & Nandwani, 2020), and similarly to Europe, migration to cities directly contributes to the continent’s urbanization (Hampwaye, 2013). Thus, urban expansion in Asia is concentrated in metropolitan areas. This population growth has resulted in a decrease in agricultural land due to conversion to other non-agricultural purposes (Akaeze & Nandwani, 2020). Moreover, it has led to decreased food availability and increased food prices (Zezza & Tasciotti, 2010). The crops grown mainly for personal use and sale in Asian cities are mostly edible. In particular, the development of urban agriculture in Asia faces several problems, such as low acreage of land or problems with land ownership and use, as well as planning constraints and, in addition, high prices, technological and infrastructural challenges related to the establishment, operation and management of such land (Van Tuijl, Hospers & Van Den Berg, 2018). Despite multiple problems, many countries and cities in Asia are prosperous in urban farming programs, for example, the Pune City Farming project, Mumbai, Delhi, as well as some programs established by numerous ventures to train and assist farmers (Akaeze & Nandwani, 2020).

The history of urban gardens – the allotment garden began in Europe in Germany (Kappeln) in 1814 (Cabral et al., 2017). Currently, there are over 2 million allotment gardens in Europe associated with the Office International du Coin de Terre et des Jardins Familiaux (http://jardins-familiaux.org). Allotment gardens can be found all over Europe, especially in Central and Northern Europe (Bell et al., 2016; Cabral et al., 2017). As green areas, they effectively complement the green infrastructure of the cities. The community garden, constituting a different form of an urban garden, has existed for 20 years as a supplement to allotment gardens that fill urban voids. These community gardens promote environmental education and social cohesion and contribute to climate adaptation. One of the triumphant histories of urban gardens is located in Lisbon, with several community gardens serving food provision, cultural services and educational opportunities, as well as enhancing green infrastructure by providing ecological corridors in urbanized areas, while in Leipzig accessibility is limited, and the garden is located on private land managed by an allotment organization. Many native species can be found in old allotment garden complexes because many plots are abandoned (Speak, Mizgajski & Borysiak, 2015; Borysiak, Mizgajski & Speak, 2017). In the popular discourse on urban gardening, there has been extensive research into the socio-economic benefits, contribution to promoting human health and well-being, and the potential to support social cohesion and spatial justice (Cabral et al., 2017; Gawryszewska, Łepkowski & Wilczyńska, 2019). However, more needs to be heard about the potential of urban gardening as a means of urban retention in the city, especially in the context of the climate crisis (Tomatis et al., 2023). Therefore, this study of contemporary literature aims to answer the following research questions:

- RQ1: Do contemporary scholars recognize the potential of urban gardening in improving urban retention?
- RQ2: What indicators have been found in the literature as crucial for enhancing urban retention? Do they form specific groups of factors?
- RQ3: Are there any disparities in the occurrence of indicators among continents?

Material and methods

Methods of material meta-analysis and data collection

Preliminary searches were conducted using peer-reviewed literature from various academic databases, including Web of Science (WoS), Science Direct (SD), Springer and MDPI – the search criteria aimed to collect papers related to urban agriculture and gardening. The search employed logic sentences using keywords, where 'OR' indicated either one or both terms and 'AND' indicated all the terms that should be present (Alberti, Bessa, Hardy, Trappman & Umney, 2018). In the identification phase, the search keywords used were 'urban garden' OR 'allotment garden' OR 'community garden', OR 'urban agriculture' combined with 'water retention'. After removing duplications, the total results obtained were as follows: Science Direct (*n* = 352), Springer (*n* = 95), MDPI (*n* = 25), and Web of Science (*n* = 875) – cf. Round 1 in Table 1.

TABLE 1. Preliminary meta-analysis of five popular academic databases

Round	WoS	SD	Springer	MDPI	Total
1	875	352	95	25	1347
2	3	211	6	0	220
3	2	144	6	0	202

Source: own elaboration.

The procedure described above made it possible to identify the recurring indicator words used by the authors: 'soil maintenance', 'rainwater/stormwater infrastructure', 'planting type', and 'watering system'. Finally, the four factors were used to refine the search. The refined results were as follows: Science Direct (*n* = 211), Springer (*n* = 6), MDPI (*n* = 0), and Web of Science (*n* = 3) – cf. Round 2 in Table 1. Green roofs were then excluded from the search to focus on ground-based urban gardens, resulting in the following results: Science Direct (*n* = 144), Springer (*n* = 6), MDPI (*n* = 0), and Web of Science (*n* = 2) – cf. Round 3 in Table 1.

After thoroughly reading the papers, only 46 were selected for further analysis considering their content relevance to the topic (Fig. 1).

Once a fine collection of literature was obtained, the next step involved filtering the retrieved results to create a binary-categorized matrix for analysis purposes.

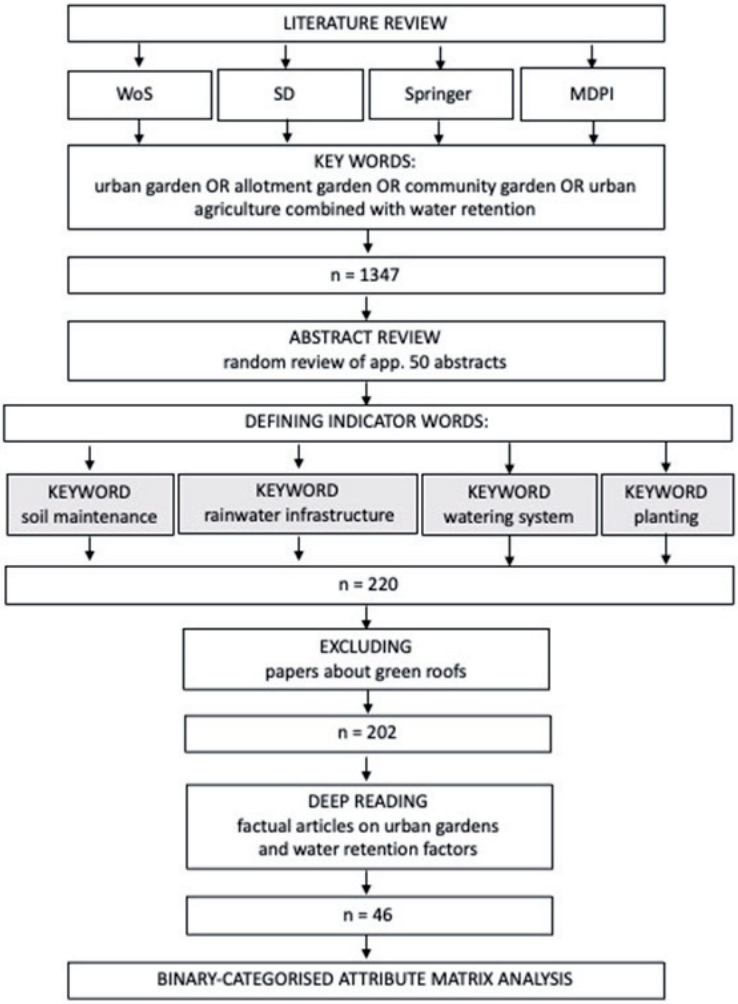

FIGURE 1. Schematic representation of the research procedure

Source: own eleboration.

Methods of data analysis

To obtain answers to our research questions, we did some follow-up work. The initial literature review was used not only to define the indicator keywords (RQ2), but also to understand the context and broader background of the formulations considered indicative. Furthermore, the clarified definitions served to further define them in detail in the subsequent stages of the meta-analysis. Both the number of articles and the case studies described in them were analyzed. Thus, the research phase ultimately helped to determine the perceived potential of urban gardening in improving urban retention by contemporary researchers (RQ1).

The data resulting from a meta-analysis in the form of an attribute matrix (binary-categorized) was further organized. The sets of attributes for the articles extracted using meta-analysis (Round 2 in Table 1) were also clustered using Ward's cluster analysis with the analytical tool R. This made it possible to identify the role of various indicators mentioned in the literature (RQ2). The number of case studies described per country and continent was determined (RQ3). The graphical representation of the dendrogram was developed with the help of the SRPLOT application available on the platform Bioinformatics.com.cn. The results were also visualized in tabular form using Microsoft Excel (version 16.56).

Water retention in urban gardens

The indicators for enhancing urban retention found in the literature

Authors show that urban gardens are dispersed in urban areas and can function more effectively than other types of green storm infrastructure (Chapman, Small & Shrestha, 2022; Ebissa & Desta, 2022). The built environment and, water-impermeable surfaces – paving, stone slabs and building roofs – increase surface runoff, contributing to uncontrolled flooding and water pollution (Miller et al., 2014). The function of stormwater retention and interception has therefore become an essential element of planning green areas in the city in order to mitigate the effects of accelerated surface runoff, especially in the event of extreme weather events resulting from climate change (Donat, Lowry, Alexander, O'Gorman & Maher, 2016; Pathak, Liu, Jato-Espino & Zevenbergen, 2017; Khurelbaatar et al., 2021; Yaduvanshi, Nikemelang, Bendapudi & New, 2021). Soil culture is also characteristic of urban gardens – rich in locally produced compost (Small et al., 2019). Characterized by porosity, they have a high-water retention capacity and evapotranspiration from garden plants grown in nutrient-rich soil (Qiu & Turner, 2013).

Although urban gardens use more water-to-water crops, seasonally observed evapotranspiration rates were almost twice as high as in areas covered with urban lawns (Saha, Trenholm, & Unruh, 2007; Monteiro, 2017). In addition, the literature claims that adding organic material can increase the water retention capacity (Young, Zanders, Lieberknecht & Fassman-Beck, 2014; Wadzuk, Hickman & Traver, 2015). Comparing the examined urban areas with different development – garden crops and urban lawns, the former, despite irrigation, were generally characterized by smaller leachates. Furthermore, Chapman's research suggests that urban gardens are more like stormwater green infrastructure, and rain gardens have outstanding water retention, infiltration and evapotranspiration capabilities regarding stormwater retention (Chapman et al., 2022). These benefits are noteworthy as urban gardens are built and maintained for other purposes, such as food production, recreation, decoration and other social benefits (McDougall, Kristiansen & Rader, 2019). Ecosystem services provided by city gardens cannot be overestimated.

A study by Chapman et al. (2022) confirms various features of urban gardens related to water retention, such as water retention and temperature reduction caused by evapotranspiration. They can provide benefits like specially designed green infrastructure. The importance of soil type in water retention in garden crops was disproportionate to the importance of the cultivated plant type (the difference between a lawn and a garden crop).

Precipitation characteristics (volume, intensity and time) and reference evapotranspiration dynamics are the most critical drivers of precipitation retention and runoff in different regions of the planet (Zhang et al., 2019). The efficiency of greenery retention in the city also depends on the properties of the substrate (De Ville, Le, Schmidt & Verbanck, 2017). Improving water storage in the soil is an important factor for healthy plant growth and subsequent yields. The authors say that short-term, high-density rainfall favored a reduction in runoff and thus increased water storage in the soil. Conversely, prolonged high-density rainfall favored reduced peak flow duration (Li, Li, Huang & Liu, 2020). The results of the study conducted by Chen, Ni, Shen, Xiang and Xu (2020) confirm that an urban garden with vegetable and fruit crops promotes the water retention effect and reduces surface runoff and peak flow duration. Types of crops and water flow in the soil can increase the water retention capacity of urban greenery, becoming an instrument of retention (Chen et al., 2020).

Regarding the literature analysis, four indicators of water retention were defined:
- soil maintenance/cultivation (using compost, mulching, perlite, etc.);
- rainwater/stormwater infrastructure (collecting rainwater water – special infrastructure);
- watering systems (system for providing water strait to plants);
- planting type (garden plants: flowers, vegetables, fruits, herbs on beds – no turf: lawn or turf with dicotyledonous plants).

Improving urban retention through urban gardening – analysis of resources of scientific literature databases

While working on the project, it became apparent that although the scientific literature covering the topic of water retention is abundant and the role of urban gardens recognized, the final number of articles on retention rates was not large. Of the 46 articles selected for the in-depth analysis, only 2 described all 4 indicators at once. Consecutively, 3 indicators were found in 5 papers, 2 in 12 and 1 in the 27 remaining papers. Regarding the occurrence of the individual indicators of retention, the indicator talking about soil maintenance and cultivation appeared in 30 papers, while the indicator on the type of planting appeared in 20. According to the authors, the predominance of these two indicators, specific to green spaces and gardens, demonstrates the vital role that urban gardens can play in a resilient urban environment. It seems to be particularly apparent in research about crop vegetation in urban gardens and agriculture (De Pascale, Dalla Costa, Vallone, Barbieri & Maggio, 2011; Reeves, Cheng, Kovach, Kleinhenz & Greval; 2014; Gregory, Leslie & Drinkwater, 2016).

On the other hand, the indicator for rainwater and stormwater harvesting infrastructure was found in 11 papers and for the watering system in 15. Here, we need to, following some authors (Gittleman, Farmer, Kremer & Mc Phearson, 2017; Kuehler, Hathaway & Tirpak, 2017; Peña, Rovira-Val & Mendoza, 2022), distinguish between rainwater and stormwater retention infrastructure. Then the issue under discussion becomes even less relevant in the results of our meta-analysis, although noted. To summarize this brief quantitative analysis, the authors are more willing to emphasize bioretention in urban gardens (Table 2).

TABLE 2. The representation of 4 defined indicators in in the final papers' set

Parameter	Soil maintenance and cultivation	Rainwater/stormwater infrastructure	Planting type	Watering systems
Indicators in total	30	11	20	15

Source own elaboration.

A dendrogram describing the grouping of the analyzed papers according to the attributes, which were the indicator attributes developed above, distinguished 2 main result groups. The first, comprising 14 papers, includes those in which we found only one indicator attribute, most often the one related to soil maintenance; in subsequent groups, this attribute is associated with further ones (Hatfield, Sauer & Prueger, 2001; Abdalla, Predotora, Gebauer & Buerkert, 2012). The next group is divided into three subgroups, containing 8 papers (articles related to the rainwater and stormwater infrastructure attribute (Amos, Rahman, Karim & Gathenya, 2018; Kopperlar, Marruglia & Rugani, 2021). Next 6 papers group articles containing soil maintenance and planting type (Chen et al., 2020; Chapman, Small & Shrestha, 2021) and the remaining 19 items, which is consistent with the number and distribution of attributes. Subsequent groups show further 'attaching' attributes. The final distribution divides the surveyed literature into 12 groups (Fig. 2).

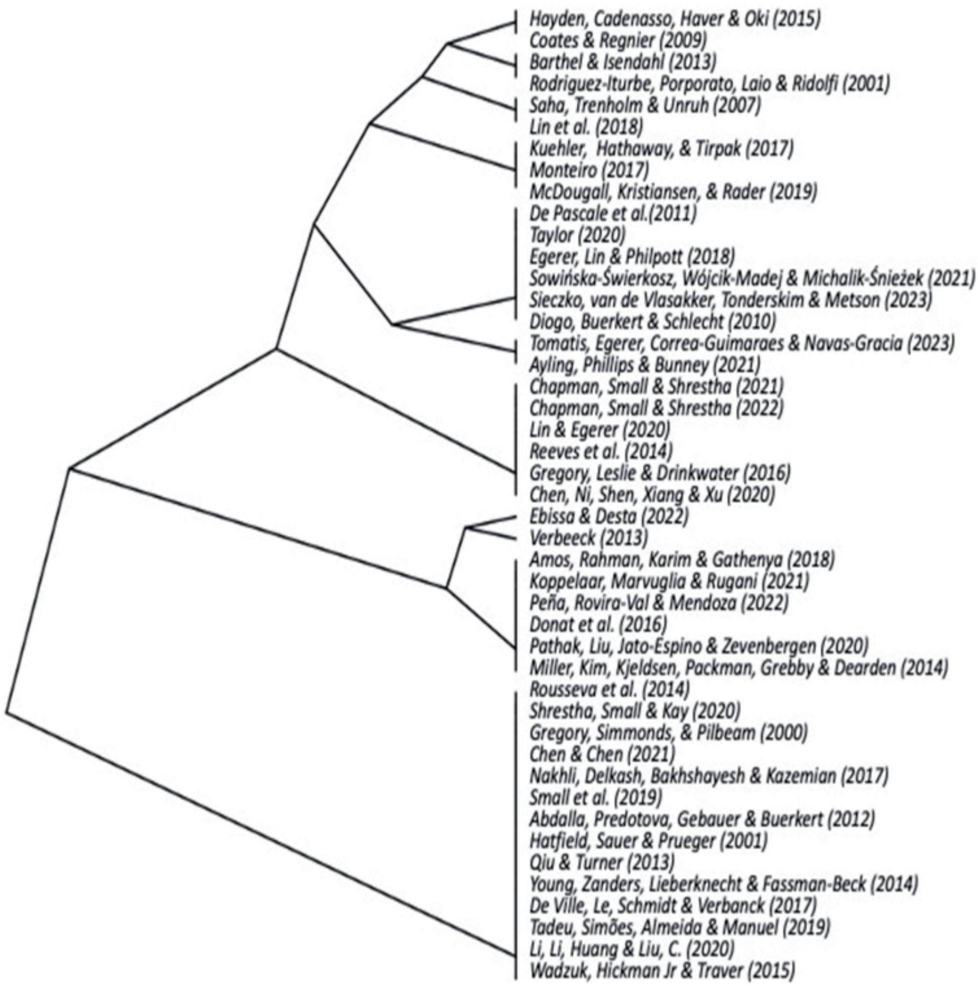

FIGURE 2. A dendrogram describing the grouping of the analyzed papers according to the attributes
Source: own elaboration.

Disparities in the indicators identified in the case studies between continents

Regarding case studies, there were 46 cases described in 39 from 46 analyzed papers. Most of the case studies cited (43.4%) were conducted in North America (Barthel & Isendahl, 2013), followed by Europe (28.3%) (Ayling, Phillips & Bunney, 2021), Asia, Australia and Oceania (8.7% each) and Africa (10.9%) in descending order. Significantly, there were no papers from South America (Fig. 3). Among the 46 articles describing cases in general there were 7 articles mentioning more than a case, including 2 within a continent (Rousseva et al., 2014; Nakhli, Delkash, Bakhshayesh & Kazemian, 2017) and 5 analyzing cases on two continents (Young et al., 2014; Egerer, Lin & Kendal, 2019; Gregory, Simmonds & Pilbeam, 2000; Koppelaar, Marvuglia & Rugani, 2021; Tomatis et al., 2023).

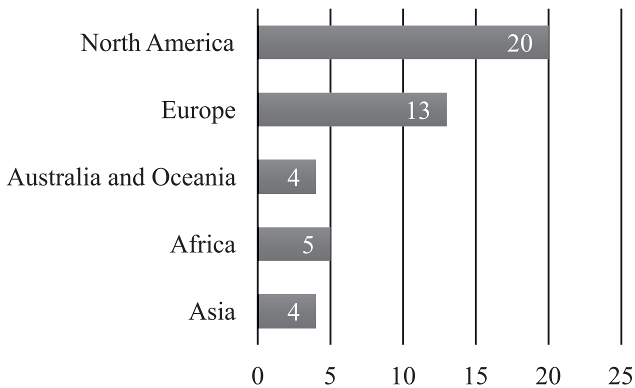

FIGURE 3. Distribution of the case studies on the continents
Source: own elaboration.

It is apparent that most cases from North America speak of indices related to soil maintenance and planting type, while indices from Europe are more evenly distributed. In contrast, it is difficult to speak of trends in the case of Asia, Africa (Diogo, Buerkert & Schlecht, 2010; Abdalla et al., 2012), and Australia and Oceania (Egerer et al., 2019; Li, Li, Huang & Liu, 2020), where the number of papers, and hence case studies described, could have been bigger. It may suggest a greater tradition of urban gardens and hence bioretention in Euro-American culture (Table 2).

Conclusions

The indicators to which we have devoted our meta-analysis of the scientific literature seem to initially summarize the most important aspects related to the scientific research carried out in this field. However, it would be worth conducting further studies, for example treating the threads related to the storm and rainwater infrastructure separately, compost and other additives to improve water retention in garden soil, as well as different types of planting and cultivation techniques. It could provide valuable guidance for urban gardeners, formulated at the scale of the garden rather than the whole city.

The most frequently mentioned indicator of an urban garden as a water reservoir is the use of compost and other additives by gardeners to improve water retention in the soil. Rainwater and stormwater harvesting infrastructure are only ranked second, usually mentioned in tandem with soil maintenance. Another indicator accompanying soil cultivation is the planting type, i.e., garden cultivation and its superiority over other types of greenery, which makes the urban garden unique among other bioretention areas.

The method adopted fulfilled its purpose, although a smaller than expected number of papers was obtained for a deep analysis. The research will undoubtedly continue, and we plan to add more keywords, e.g., sponge city and water resilient city, to broaden the number of results obtained. We also consider adding the scientific search engine Scopus and the ResearchGate and Academy portals. The latter will help to broaden research with grey literature. It will also help to reduce the risk of terminological differences possible between studies conducted on different continents.

The concept of the urban garden as a reservoir in water retention has been present in the scientific literature for years. Although observations have been made on a small sample, the North American literature, in particular, abounds with case studies summarizing the treatment of the urban garden as a retention tool in urban areas. Noticeable is the lack of representation of South America, if only because of its geographical proximity, which is worthy of more profound research. The paper can contribute to developing the first recommendations for urban gardeners and local authorities on the management and development of urban gardens, such as allotments and community gardens, considering their role as a retention tool.

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Summary

Urban garden as a water reservoir in an urban area – a literature review. The aim of the presented work was to show that contemporary researchers recognize the potential of urban gardening in improving urban retention, and that the contemporary scientific literature mentions specific problems-indicators of retention that can be useful for developing guidelines for authorities and gardeners on the management and development of urban gardens,

such as allotments and community gardens, considering their role as a retention tool. In this study, a meta-analysis of peer-reviewed scientific articles from popular scientific databases such as Web of Sciences, Science Direct, Springer and MDPI was performed, which was, besides literature analysis, the main method of research. Definitions of urban garden retention indicators were developed, which are: rainwater/stormwater infrastructure (collecting rainwater water – special infrastructure); watering systems (system for providing water strait to plants); planting type (garden plants: flowers, vegetables, fruits, herbs on beds – no turf: lawn or turf with dicotyledonous plants). The most frequent groups of indicators in the articles were also identified. The study also analyzed the distribution of surveyed articles between continents, noting the overrepresentation of articles from North America and the absence of articles from South America.