MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

Rocznik Ochrona Środowiska

Volume 21. Year 2019 ISSN 1506-218X 1263-1278

Current Status and Possibilities of Implementing Green Walls for Adaptation to Climate Change of Urban Areas on the Example of Krakow

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1. Introduction

Extreme weather conditions such as: high temperatures, heat waves, torrential and heavy rains, strong winds or floods are increasingly frequent symptoms of climate change. As predicted by climatologists, they would keep occurring more and more often and their intensity would increase. Expansion of the cities resulting in a continuous annexation of biologically active areas under housing developments, parking lots, recreation and educational centers, shopping centers etc. is considered as the main cause of climate change. By 2050, almost 70% of the world's population (around 6.4 billion people) is to live in cities and urban areas, meaning that the number of city dwellers will almost double (International Organization for Migration 2015). Modifications of the climate, caused by urbanization and industrialization, become the topic of concern mainly because of increased air pollution, radiation (changes in components of a radiation balance), thermal and humidity conditions, air circulation (change of direction and speed of wind) and precipitation.

Each city faces particular climate threats, specific to its structure and conditions, e.g. high temperatures (a regular increase of the average annual temperature is observed, e.g. by 1.2°C in the period 1951-2010), volatile rains (increase of annual rainfall by 10-15%). Climate changes cause also water deficit and a development of invasive species, which pose a threat to human health. The higher number of illnesses is also associated with i.e. heat waves – the results of Polish research show an increase of mortality by 18% due to cardiovascular diseases, as a result of extremely high temperatures (Institute of Environmental Protection – National Research Institute 2017).

Since 1850, 13 out of the 14 warmest years fall on the 21st century and each of the last three decades has been warmer than the previous one (World Meteorological Organization 2014). Flooding and floods are the biggest threats to the agglomeration. They pose a great danger not only directly to residents' property, but also cause severe economic losses, e.g. during a temporary interruption of a production process.

Cities are an unique kind of ecosystem where people, infrastructure and nature should co-exist in a harmony. The challenge, however, is to direct the city development so as it positively impacts all areas of life, including the quality of the natural environment. The main strategic activities for cities should be included in plans for their spatial development. The plans should underline the need to increase green areas and waterways as well as ventilation corridors. Urban adaptation plans should take into account rainwater management and higher retention.

In the era of modern cities, sustainable spatial planning becomes a considerable challenge for urban planners. The need to adapt existing urban areas to climate change is also not an easy task. This is particularly difficult in historic city centers, where implementation of many technical solutions is very much limited. Adaptation of cities to climate change, and in particular to its effects, is described in (Ministry of the Environment 2014) as a stronger resilience of society and the economy to negative effects of current and anticipated climate change. The document (The Intergovernmental Panel on Climate Change IPCC 2014) defines adaptation as the process of adjustment to actual or expected climate and its effects. In Poland, the first strategic document on the issue of adaptation to climate change was the “Strategic adaptation plan for sectors and areas sensitive to climate change by 2020 with the perspective of 2030” (so-called SPA 2030), developed on the basis of the KLIMADA research project (Ministry of the Environment 2014).

One of the proposed solutions for adapting cities to climate change is introduction of various forms of green infrastructure. Water and greenery, so called blue and green infrastructure, perfectly fit into the urban space; it deals with adverse symptoms of climate change in a very positive way, based on the forces of nature.

The source (Ministry of the Environment 2015) gives an example how the area at risk of urban flooding can adapt to climate change by namely growing green infrastructures, especially green roofs and walls. This is a "win-win" option, which means that additional social, ecological or economic benefits are also obtained in mitigating the effects of climate change (Ministry of the Environment 2015).

Green roofs have been a topic of research and numerous scientific studies for many years. In the scientific literature (Perini & Rosaco 2013, Sheweka & Magdy 2011, Djedjig et al. 2017) one can also find studies on living walls, although this topic is not as popular as green roofs. Designing of green roofs on the existing buildings in the urbanized area is not an easy task since it has to consider e.g. the strength of the building's structure. It should be noted that since there is less horizontal surfaces in the city than vertical ones and since the green wall can also be installed on fences or screens – there is a great potential for placing them in public places. Linear or pocket parks, that have been recently popular, are a good example how green walls can find their place in the city space.

The paper analyses the role of green walls in the adaptation of urban space to climate change. The authors developed a map of locations of this type of green infrastructure in the city to indicate potential sites for new plantings.

2. Definition of green walls

There are many definitions of green walls in the technical literature and scientific studies. There are also various definitions of vertically grown vegetation. These include names such as: green facades, living walls and vertical gardens. For example, according to (City Council of Wrocław 2015), a vertical garden is an installation with perennial plants located on the substrates enabling their multi-season vegetation. According to (Future Cities Adaptation Compass 2018), the green wall is a wall covered with vegetation. It should be noted that the term "wall" can mean a wall made from bricks or stones or a fence. According to (Kania et al. 2013), the term "vertical plants" can refer to both walls covered with vines planted in the ground, as well as plants mounted vertically in special constructions. Usually, the authors explain the definition to which they refer in their work. Terminology needs to be further thought out and organized in this respect, but such approach requires a broad scientific discussion and consultation or even adopting a legal act (standard).

The authors suggest that all kinds of vertical structures and partitions covered with vegetation should be treated as green walls. This type of construction can include building walls, various types of fences – stone walls, fences or wire mash fences, as well as noise barriers, trusses, frames, balustrades, retaining walls and shed walls. Also a special kind of green walls, where the plants are arranged vertically on an individual construction, is considered as a vertical garden. Among the accepted green walls concept, outdoor and indoor walls can be included.

In the paper, only outdoor walls are be considered, as they may be an important element of adaptation of the city to climate change. The outdoor green walls can be attached to a building structure or just free-standing (all fences, pergolas or

screens). It should be added that there are also special racks, installed in such a way as to maintain a certain distance between plants and a building.

There are also hanging green walls, e.g. from balconies or billboards. They do not related in part to any surface. Another issue are lighting poles, trees or advertising poles covered with vegetation. In their case, green poles seems a more accurate term.

3. Role of green walls

Vertical gardens combine many functions and are a good practice in developing of an urban space. They are natural elements of the urban environment that have a positive impact on many aspects (Burszta-Adamiak 2015, Cahill 2012, Kania et al. 2013).

The importance of green walls for the design of urban space is also determined by the fact that proposal of technical standard for them can be found in the technical literature (Tedesco et al. 2016, Giordano et al. 2017).

Green walls create a healing environment and green plants accelerates a process of recovery for hospital patients (shorter hospital stay). They bring solace, improve well-being and create a healthy atmosphere in the room. Ailments, such as eye irritation, headaches, sore throat or fatigue are significantly reduced in these areas. In offices with a lot of greenery, a noticeable drop in absences caused by diseases has been observed.

Vertical gardens can provide an interesting decorative element, as well as hide old and ugly walls.

They compensate for green areas lost during city development and introduce vegetation to the city center, without taking up the land surface.

Green systems such as green facades or living walls may contribute to reduction of effects of the urban heat island and improve air quality (Perini & Rosaco 2013). As each greenery, they improve the air quality and therefore they are called "city lungs ". Plants located on green walls filter dust that fly in the air and convert CO_2 into oxygen.

Green walls are an excellent acoustic isolator. According to research (Azkorra et al. 2015), a weighted sound reduction index for the tested type of green wall was obtained at the level of 15 dB.

Green walls provide a thermal insulation of building facades, so electricity bills for air-conditioning can be much lower. They also help to eliminate negative effects of the urban heat island. A detailed literature review on these issues can be found in (Sheweka & Mohamed 2012). In turn, (Djedjig et al. 2017) describes an experiment carried out to understand the thermal and hydrological behavior of green walls.

Thanks to vertical gardens biodiversity in the environment is expanding; plants growing on green walls provide a perfect shelter for birds, butterflies and other insects.

In water management, blue-green infrastructures, including vertical gardens, are an important element of effective rainwater management in the city both in case of water excess or shortage. Green and blue infrastructures work closely together: vegetation is a biological reservoir of water while water is essential for a vegetation growth. In addition, plants that are one of the elements of the blue-green infrastructure, uptake a certain amount of water from the root zone and evaporate it into the air (evapotranspiration). Green walls, although to a limited extent, but play a role in managing rainwater in cities (Burszta-Adamiak 2015). They stop, among others, runoff water (Januchta-Szostak 2011).

Vertical gardens are a solution that reduces and slow down the outflow of rainwater to sewage systems. Too fast and sudden discharge to a sewage network is currently the most important problem of rainwater management in the cities.

Positive impact of vertical gardens on the urban environment may not be as important as green roofs, but assuming their use on a large scale – the effect may multiply.

4. Scope

The aim of the research was to find locations of green walls in the city of Krakow and then visually assess their spatial structure and density. On the basis of this data, areas for potential growing of green infrastructures in a selected settlement unit were identified.

The authors also created a map of green walls in Krakow along the main communication routes. The map is made up of spatial data in a digital form, as two vector layers linked with the city map.

5. Materials and methods

The research material comprised the map of Krakow and information obtained during a preliminary inventory of the Krakow's green walls.

Due to a large number of green walls in Krakow, the scope of work was limited only to the first, second and third ring around the city (existing sections) and to major roads and their immediate vicinity.

The first ring included the following streets: St. Idzi, Podzamcze, F. Straszewskiego, Podwale, J. Dunajewskiego, Basztowa, Westerplatte and St. Gertruda and their closest vicinity. The second ring comprised the streets: M. Konopnickiej from the Mateczny roundabout, the Alleys of Trzech Wieszczy, part of the Alley of 29 Listopada, W. Stwosza and A. Lubomirskiego, Powstania

Warszawskiego, Kotlarska, G. Herlinga-Grudzińskiego, S. Klimeckiego, Powstańców Wielkopolskich, the Alley of Powstańców Śląskich, part of H. Kamieńskiego up to the Mateczny roundabout. The third ring comprised: part of Armii Krajowej, street of J. Conrada from the Ofiar Katynia roundabout, streets: Opolska and Lublańska, the Alley of general T. Bór-Komorowski, streets of I. Stella-Sawickiego and Nowohucka. The remaining part of this ring is just planned and currently does not exist. The only exception is the section covering streets: Nowosądecka and W. Witosa, which was also included in the research.

In addition to the rings, some major city routes were also taken into account, including the streets: Mogilska, the Alley of Jan Paweł II, the streets R. Kuklińskiego – Lipska – J. Surzyckiego – Rybitwy – Ch. Botewa, the streets Młyńska and J. Meissnera, the Alley of 29 Listopada up to the general T. Rozwadowski overpass, Armii Krajowej, streets: S. Grota Roweckiego, M. Bobrzyńskiego – K. Bunscha, and also the Alley of Pokoju, the streets: H. Kamieńskiego and Wielicka (up to Nowosądecka) and their closest vicinity.

The map of Krakow's green walls has been completed on the basis of cartographic data from OpenStreetMap.org (Geofabrik 2018, OpenStreetMap 2018). In addition, the materials form the state geodetic and cartographic resources were used. The data from the state register of boundaries and the area of units of territorial divisions of the country were collected (Head Office of Geodesy and Cartography 2018). The map was developed using the QGIS program – version 2.4.0 (QGIS 2015).

New spatial data has been added to the map. Two vector layers in a form of points were created. The first layer corresponds to buildings (or other constructions) with green walls, the other one marks free-standing green walls, i.e. fences or acoustic screens. Each point is described by the list of specific features, including the ordinal number, the name of the street where the wall is located, the wall number (if there is more than one) and any other comments. Due to the use of two separate layers, it is possible to create two separate maps (with specific types of green walls) or one combined map.

Green walls attached to balustrades of terraces or balconies were classified as green walls of buildings. In the case of streets with a large number of screens, it was assumed that each sequence of screens with vegetation corresponds to one point on the map. When there were more screen sequences or gaps in between, then another point on the map was added with a corresponding annotation in the table of features. The maps do not include green walls at public transport stops.

The research was conducted for a long period of time and over different seasons. A photographic documentation was collected for the green walls, showing vegetation during both a growing and a resting season.

6. Discussion of results

In the studies, a relatively large number of external green walls was spotted along the streets in question (Fig. 1).

There were just a few plant species planted on the green walls, mainly ivy like, e.g. ivy and Boston ivy. However, a large variety of constructions on which vegetation occurred was observed. Creepers were found on noise barriers, wire mesh fences, fence walls, retaining walls, special racks, as well as billboards and street lamps. In the case of buildings, the plants also covered balustrades and balconies. Both evergreen and the plants losing leaves were represented. Figures 2 and 3 show a green wall during resting and vegetation periods. The plants that change color rather than flourish have been observed more often. On the other hand, there were no green outdoor walls in the public space, such as vertical gardens.

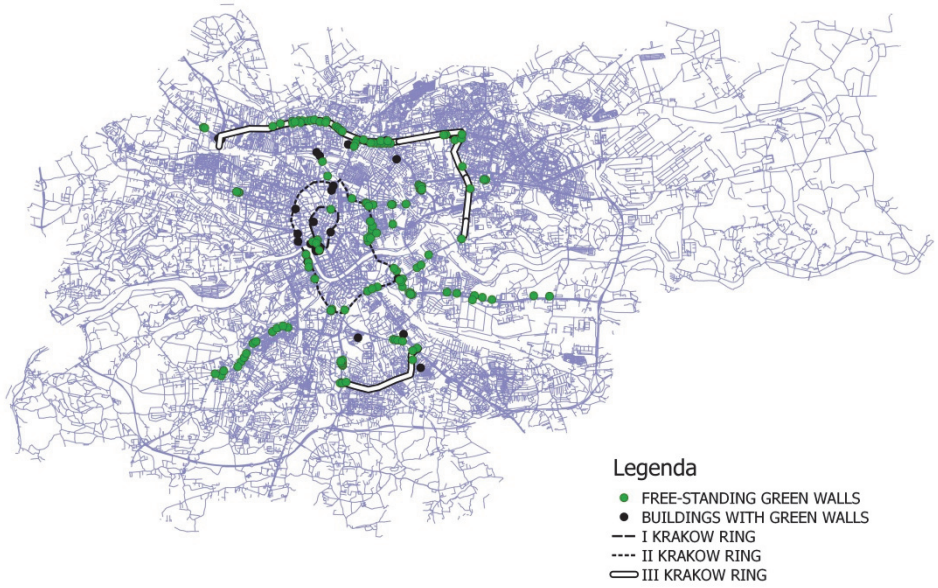

Fig. 1. Map with a location of green walls along the major routes in Krakow. Study based on own data and data from (Geofabrik 2018, Head Office of Geodesy and Cartography 2018, OpenStreetMap 2018)

Fig. 2. Green wall in a resting season (author's photo)

Fig. 3. Green wall in a vegetation season (author's photo)

Along the first ring (a sequence of streets surrounding the Old Town) vegetation can be found only on individual structures (walls, fences, screens) mainly in the south-western part of the area. There are also few vines on the walls of buildings. Green walls can be mainly found on many historic buildings located at the Wawel Hill. There are not many examples of green walls in this area, however there are other different forms of greenery e.g. Planty surrounding the Old Town and numerous gardens. Therefore, it does not seem necessary to set up new green walls, although each new plant in urban space generates additional environmental gains. The layout of the green walls along the first ring is shown in Figure 4.

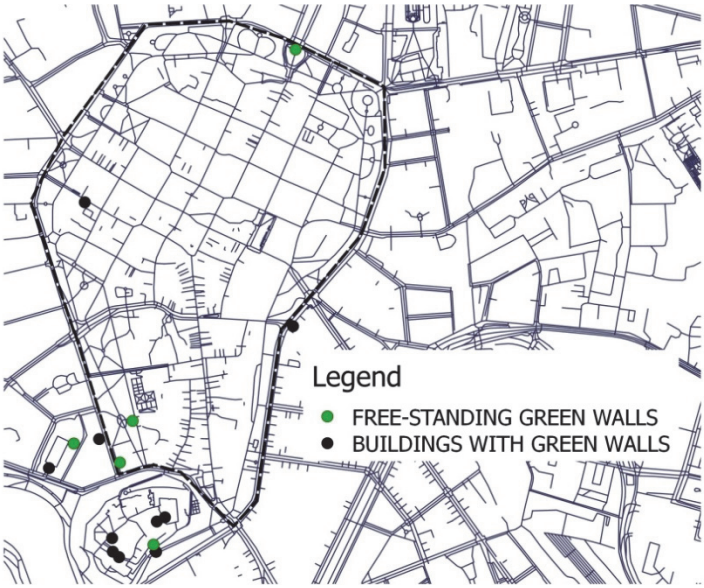

Fig. 4. Green walls along the first Krakow ring – Study based on own data and data from (Geofabrik 2018, Head Office of Geodesy and Cartography 2018, OpenStreetMap 2018)

The second ring is a series of city streets along which green walls can be seen. The green walls are placed quite evenly in fragments of this ring of roads, with an exception of the northern part. Almost every street in this district has green walls on buildings or as a detached structure. However, they are quite rare. The evergreen wall on the Mogilskie roundabout, incorporated into the historic fort ruins, deserves a special attention in this area. Figure 5 shows the city map with the green wall locations along the second ring.

Fig. 5. Green walls along the second Krakow ring – Study based on own data and data from (Geofabrik 2018, Head Office of Geodesy and Cartography 2018, OpenStreetMap 2018)

It is therefore proposed to densify the existing green infrastructure, especially in the northern and north-western parts of the second ring road. The potential location of green walls in this area may be tenement houses along Słowackiego Avenue and Mickiewicza Avenue (if the condition of their facades is good). A characteristic feature of these buildings is the large facade surface. The buildings of technical universities (AGH University of Science and Technology, Cracow University of Technology, University of Agriculture) located in this area can also be a location for new green walls. It can be added that in the analysed region of the second Krakow ring there is greenery along the Avenues of the Three Poet – Prophets, but every new form of greenery in the built-up city center is important. In the south-west part of the second road ring, green walls can be introduced in the new housing estate on the Wilga River, while in the east and south part of the second beltway it is suggested to introduce vegetation on all existing sound absorbing screens. In addition, the city has already attempted to introduce green walls at public transport stops around the second ring road, but they were not included in the maps due to their very small size.

Among the existing sections of the third ring, a beautiful corridor of green walls along the Opolska Street can be noticed. The street has two roadways with three lanes in each direction. The roadways are separated by a green belt and partly by noise barriers. Vegetation covers noise barriers on both sides of each roadway. Another green walls (on screens and fences) are placed also along the next street (continuation of this section). The roads constitute the central part of the northern part of the third ring. Single screens are located in the north-eastern part of the ring and at both ends of the existing southern section. Moreover, single fences covered with vegetation were observed along the third ring.

A striking lack of greenery was observed on the western section of the northern ring. The green walls should be mainly considered in this area – for example on numerous shopping centers located in this area or their fences. The use of green walls should also be considered on the eastern section of the northern part of the ring, also with shopping centers. It is proposed to introduce green walls or green roofs for Krokus and Serenada shopping centers, Galeria Bronowice and a large furniture store located near the northern part of the third road ring. Along the eastern part of the third ring more green fences should be placed as well as more noise barriers covered with vegetation. It is also proposed to build green walls along the southern section of the third ring. Figure 6 shows the city map with the green wall locations along the third ring.

Among the more important communication routes, there are single green walls on fences or screens. Particularly noteworthy are sequences of screens planted with vines stretching from Kuklinski street to Botewa street and from Grot-Rowecki street to Bunsch street. It seems that the greening of all noise barriers along the city's main communication routes is the right direction. It is possible to try to encourage property owners along the city's major routes to introduce vegetation on theirs fences.

A worth mentioning cluster of green walls can be found around the University of Agriculture, where creepers are present on a long noise barrier, on the walls of a sports hall, and also on two fences, located nearby. Green walls are also present on several objects located at the campus of the Cracow University of Technology.

Fig. 6. Green walls along the third Krakow ring - Study based on own data and data from (Geofabrik 2018, Head Office of Geodesy and Cartography 2018, OpenStreetMap 2018)

7. Conclusions

Installation of green roofs on existing buildings is very limited due to strength of their construction. For this reason, it is extremely important to pay more attention to the issue of green walls in urban space.

The map of green walls along the most important communication routes in Krakow allowed to identify potential places for new plantings and to assess a spatial structure of green infrastructure. The spatial structure of the green walls is diverse in Krakow. In the entire city, it can be assumed that a spatial distribution of green walls associated with buildings or other structures is rather random and in some areas numerous structures can be observed (e.g. the Wawel Hill, the University of Agriculture and the campus of the Cracow University of Technology). Greenery growing on sound-absorbing screens along roads is arranged in a planned manner and its spatial structure can be treated as even (at selected street routes).

More than 140 green free-standing walls and nearly 30 such facilities attached to buildings or other structures were listed in the study. There is a large number of green walls in the city, but their density is not large, yet. There are many places that are potential locations for greening. Particular attention should be paid to shopping centers, as there are many ways to introduce this form of green infrastructure in their area. The sheds of public transport stops are also a space that can be developed through vegetation. It would be a very good solution, especially in the built-up city center. The green stops can be used especially where the implementation of green walls on other objects is difficult. It is advisable to introduce vegetation on all sound-absorbing screens. It is also worth considering the possibilities of persuading property owners to introduce greenery on fences along roads. In the discussion of the results, the areas for greening were suggested in detail, and the proposed specific locations of objects where it is worth considering the use of green walls.

Only if at a high density, greenery will help to overcome effects of climate change in the city. Creepers are the perfect plants for planting in cities. They produce green elevations, embellish buildings and isolate residents from traffic nuisances. They become green screens among the city's buildings.

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Abstract

Extreme weather events such as: high temperatures, heat waves, torrential and heavy rains, strong winds or floods are increasingly frequent symptoms of climate change. As predicted by climatologists, they would keep occurring more and more often and their intensity would increase. Flooding and floods are the biggest threats to the agglomeration. They pose a great danger not only directly to residents' property, but also cause severe economic losses, e.g. during a temporary interruption of a production process.

Adaptation to climate change can be supported not only by new technologies, but also by some trends in spatial planning, i.e. activities related to installation of green infrastructure throughout the city. Water and green perfectly fit into an urbanized space.

The article investigates how green walls can participate in adaptation of the city of Krakow to climate changes. The term of the green wall was also discussed and the own its definition was proposed.

The aim of the research was to find locations of green walls in the city of Krakow and then visually assess their spatial structure and density. On the basis of this data, areas for potential growing of green infrastructures in a selected settlement unit were identified.

The research material comprised the map of Krakow and information obtained during a preliminary inventory of the Krakow's green walls. The map of Krakow's green walls has been completed on the basis of cartographic data from OpenStreetMap.org. In addition, the materials form the state geodetic and cartographic resources were used. The map was developed using the QGIS program – version 2.4.0.

The authors created a map of green walls in Krakow along the main communication routes. The map is made up of spatial data in a digital form, as two vector layers linked with the city map. There were just a few plant species planted on the green walls. However, a large variety of constructions on which vegetation occurred was observed.

The map of green walls along the most important communication routes in Krakow allowed to identify potential places for new plantings and to assess a spatial structure of green infrastructure.

There is a large number of green walls in the city, but their density is not large, yet. There are many places that are potential locations for greening. Particular attention should be paid to shopping centers, as there are many ways to introduce this form of green infrastructure in their area. Only if at a high density, greenery will help to overcome effects of climate change in the city.

Keywords:
rainwater, green infrastructure, green wall

Stan obecny i możliwości implementacji zielonych ścian w celu adaptacji do zmian klimatu terenów zurbanizowanych na przykładzie miasta Krakowa

Streszczenie

Ekstremalne zjawiska pogodowe takie jak okresy wysokich temperatur, fale upałów, ulewne i nawalne deszcze, silny wiatr czy powódź to coraz częściej występujące objawy zmian klimatu. Zgodnie z przewidywaniami klimatologów będą występowały częściej, a ich intensywność będzie wzrastać. Największym niebezpieczeństwem dla aglomeracji są podtopienia i powodzie. Mają one negatywny wpływ nie tylko na stan mienia mieszkańców, ale mogą także powodować dotkliwe straty gospodarcze, np. w postaci czasowych przerw w produkcji.

Adaptacji do zmian klimatu sprzyjają zarówno nowe technologie, jak i trendy w planowaniu przestrzennym takie jak działania związane z instalacją infrastruktury zielonej w mieście. Woda i zieleń doskonale wpisują się w zurbanizowaną przestrzeń miejską. W artykule przedstawiono stan obecny i możliwości implementacji zielonych ścian w celu adaptacji miasta Krakowa do zmian klimatu. Przedyskutowano także definicję zielonej ściany i zaproponowano własną.

Celem prowadzonych badań było określenie lokalizacji zielonych ścian na terenie miasta Krakowa oraz ocena wizualna struktury przestrzennej i zagęszczenia tego typu obiektów. Na tej podstawie określono obszary do potencjalnego zazielenienia tego typu formą zielonej infrastruktury w wybranej jednostce osadniczej.

Materiał do badań stanowiła mapa Krakowa oraz informacje pozyskane na podstawie prowadzonej wstępnej inwentaryzacji zielonych ścian Krakowa. Mapa zielonych ścian Krakowa została opracowana na podstawie danych kartograficznych pochodzących z OpenStreetMap.org. Ponadto do przygotowania mapy wykorzystano także materiały państwowego zasobu geodezyjnego i kartograficznego. Mapę opracowano z wykorzystaniem programu QGIS w wersji 2.4.0.

Określone cele osiągnięto poprzez stworzenie mapy zielonych ścian na terenie Krakowa wzdłuż głównych ciągów komunikacyjnych. Opracowana mapa stanowi dane przestrzenne w formie cyfrowej w postaci dwóch warstw wektorowych połączonych z mapą miasta. Gatunki stosowanych roślin wykazywały niewielkie zróżnicowanie. Zaobserwowano natomiast dużą różnorodność konstrukcji, na których występowała roślinność. Analiza opracowanej mapy lokalizacji zielonych ścian wzdłuż ważniejszych ciągów komunikacyjnych Krakowa pozwoliła na wskazanie potencjalnych miejsc dla nowych nasadzeń oraz ocenę struktury przestrzennej tego typu formy zielonej infrastruktury.

W mieście występuje duża liczba zielonych ścian, ale ich zagęszczenie nie jest jeszcze duże. Istnieje wiele miejsc będących potencjalnymi lokalizacjami do zazielenienia. Szczególną uwagę należy zwrócić na centra handlowe., gdyż w ich okolicy istnieje wiele możliwości do wprowadzenia tej formy zielonej infrastruktury. Zieleń w mieście pozwoli na uzyskanie niwelacji skutków zmian klimatu dopiero przy dużym jej zagęszczeniu.

Słowa kluczowe:
woda deszczowa, zielona infrastruktura, zielona ściana