Rain Gardens as Green Support of Urban Stormwater Infrastructure

Kamil Rawski*

Bialystok University of Technology, Faculty of Civil and Environmental Engineering, Landscape Architecture Teaching Team
ul. Wiejska 45E, 15-351 Białystok, Poland. E-mail k.rawski@pb.edu.pl

(Received in January, 2018; Accepted in April, 2018; Available Online from 8th of May, 2018)

Abstract

In this paper the issue related to designing rain gardens in urban space has been presented. There were found and described solutions that increase water retention and infiltration by increasing the emphasis on designing and developing green infrastructure. This approach to design allows for sustainable management of rainwater and brings other benefits. In Poland, this idea becomes more popular, but these solutions are still not widely used that is showed on example of Bialystok city (Poland).

Key words: *urban infrastructure, green infrastructure, green stormwater infrastructure, rain gardens.*

Аннотация

В статье рассмотрены проблемы проектирования дождевых садов в городской среде. Были найдены и описаны решения, которые способствуют удержанию и проникновению воды, благодаря проектированию и разработке зеленой инфраструктуры. Такой подход к проектированию позволяет устойчиво управлять дождевой водой, а также дает другие пользы. В Польше данная идея набирает популярность, однако подобные решения до сих пор не получили широкого применения, о чем свидетельствует пример города Белостока (Польша).

Ключевые слова: *городская инфраструктура, зеленая инфраструктура, дождевые сады.*

Introduction

Continuously increasing of urbanization provides to increased share of impervious surfaces at the expense of permeable. It happens due to increased demand for areas that are utilizing for housing, industry, community services or other economic functions (Vandermeulena, Verspecht et al., 2015; Xu, Chen et al., 2015; Ishimatsu, Ito et al., 2017). It was estimated that the coverage of impervious surfaces can range from 20 % in residential areas to as much as 85 % in commercial areas (Dietz and Clausen, 2005). Lack of guiding the sustainable development principles with rapid urbanization can generate many problems in a relatively short time. One of them may be the problem with rainwater management (Kozłowska, 2008).

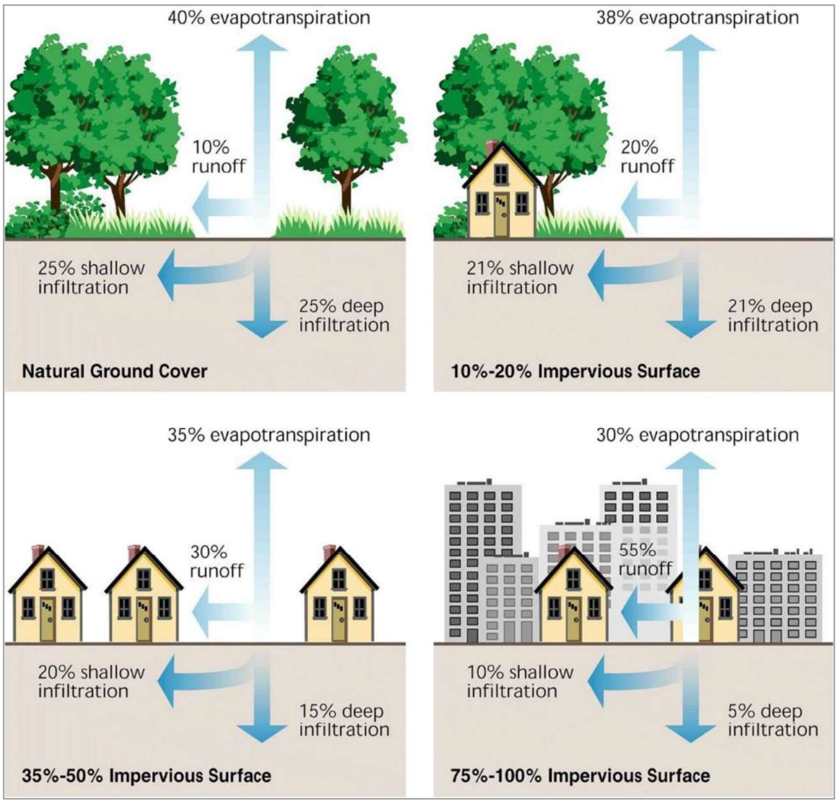

Fig. 1. Relationship between impervious surface cover and surface runoff (Federal Interagency Stream Restoration Working Group, 1998)

In urban areas, up to 70 % of rainwater can be irretrievably lost through high-efficiency

* Kontaktinis asmuo / Corresponding author

sewage systems, while on the natural areas, even 90 % of rainwater can remain in the landscape covered by the rainfall (Wagner et al., 2013) (Fig. 1). In the spatial planning and designing of Polish cities, much more attention is still paid to the effective drainage of water than to manage it on the site, where it could be collected (Januchta-Szostak, 2014). In urban areas, rainwater is treated as an intruder. The complex stormwater sewer systems with high capacity are being built in order to drain it. The same thing concerns both surface and underground water, which can be also removed through numerous drainage systems. Excessive water usually goes to nearby rivers and reservoirs in this way (Kosmala, 2003). In consequence, such behavior is detrimental to the environment (Kosmala, 2003; Kozłowska, 2008; Szuba, 2008; Bogacz i Woźniczka, 2013; Katsifarakis, Vafeiadis et al., 2015; Mehring and Levin, 2015; Ishimatsu et al., 2017). The lack of reuse of rainwater and its drainage to receivers where it cannot be treated is certainly a major problem. A good solution is to support traditional methods of water drainage by developing green infrastructure that increases processes of infiltration and retention (Burszta-Adamiak, 2012; Wagner i Krauze, 2014).

Green infrastructure is a technical term that in the 1990s concerned projects and structures in which particular significance was attributed to the use of natural elements. Currently, green infrastructure is one of the concepts of sustainable space design in order to protect the community from disasters caused by rainfall such as floods and various weather anomalies. The more intense and more frequent storms that are results of global climate change are particularly the problem. There is also known the approach that green infrastructure is not designed at all, but simply consists of natural elements preserved in the landscape, such as plants, soils and water reservoirs (Połucha, 2013).

At the national or regional level, it is a complex system of interconnected spaces with natural or designed greenery that act as green islands and ecological corridors. They enable water management and they are a habitat for various animal species. It can be said that green infrastructure helps maintain a balance between built up areas and the natural environment. At the urban level, it includes parks and forest areas that are a source of clean air and have significant meaning in reducing energy costs. In the smallest scale it is represented by green roofs and walls and other technical solutions in architectural objects that contribute to energy saving and reducing rainwater runoff (ASLA, 2012; Wagner et al., 2015). In practical terms, the idea of green infrastructure usually relays in building new, functionally designed landscape spaces that serve to absorb runoff and rainwater treatment, also to reduce flood waves. This issue includes also the rain gardens.

Methods

On the basis of Polish and foreign literature of the subject, issues related to green infrastructure, in particular to rain gardens and their impact on rainwater were characterized. The issues of problems caused by excessive drainage of rainwater through sewer systems in the environmental context were also discussed. Furthermore, the benefits of rain garden design are described in relation to the principles of sustainable development and to the economic aspects. There is also diagnosed the local problem of the increasing number of impervious surfaces in Bialystok (Poland) and the consequences associated with it. Good practices from the country and abroad, which should be duplicated, were also indicated to solve such problem.

Results

Rain gardens. Rain garden is a term that is commonly used to describe the planting of plants in the ground or container, which remove impurities from running off rainwater collected from the surface of roads, squares and roofs (Śmietańska, 2012). In practice, this is a slightly lowered

* Kontaktinis asmuo / Corresponding author

(naturally or by man) green area in relation to the environment that is planted with native plant species that helps retain and infiltrate rainwater from roofs, roads, parking lots, promenades, etc. It acts by storing rainwater (that is supplied or flowing to rain garden) that afterwards is submitted to natural filtration process by the plants and soil of the garden (Długozima, 2009; Autixier, Mailhot et al., 2014; Katsifarakis, Vafeiadis et al., 2015). Not only plants but also the common faunal inhabitants of rain gardens have positive effects on its functional (Mehring and Levin, 2015).

Nevertheless, rain gardens cannot be created anywhere. There are some restricting rules that assume that distances between those gardens and adjacent buildings should be large enough (minimum 3 m are usually recommended) to avoid water infiltration to underground structures. Rain gardens should also not interfere with utility networks and construction over septic tanks should be avoided too. It is important that underlying aquifer should be low enough to allow draining of rain water. The more densely built areas are the harder to meet these guidelines. Also surfaces with large slope are not completely suitable for rain garden construction (Katsifarakis, Vafeiadis et al., 2015). If the fulfillment of some guidelines, such as the distance to the building cannot be met, additional precautions must be taken into account during designing to ensure adequate isolation.

Plant selection. The most important assumption is the use of plants whose requirements are compatible with the specific habitat. Domestic species are the best for this purpose, but the selection of plants with foreign origin, which met to the light, thermal and soil requirements allows to prepare plantings of a naturalistic character. In this way the composition can be more varied with increasing its aesthetic qualities. Plants should be chosen to be able to grow freely, with practically no interference, though under the care of a gardener. All species should be combined so as to limit competition between them, especially when it comes to light access. Secondly, the role of the chosen plant in the garden is important (Stawicka, 2010; Katsifarakis, Vafeiadis et al., 2015).

When planning the selection of plant species, the depth of the groundwater table and the grain size of the substrate should be determined. Instead of grass surfaces, cover plants should be used if possible. When planning planting, two zones with vegetation should be distinguished - lower and upper. On the lower side should be planned the plants with better resistant to high humidity and those which can withstand periodic flooding. While, in higher zone, the plants that require slightly lower soil moisture. It is also important to plant different types of plants, because monoculture plantings are more susceptible to the effects of pests (Długozima, 2009). It is recommended to use perennial plants so as to eliminate the need for planting every year, which can causes movement of drainage layers. It is also recommended that at least 50% of plants that are planted in a rain garden should be hydrophytes that have the feature of absorbing pollutants (Domanowska i Kostecki, 2015). Designing rain gardens in highly urbanized areas is additionally related to the planning of plants resistant to air pollution. If the rain garden have to be located along communication routes (e.g. in lanes between roadways), it should be taken into account that in order to capture rainwater from streets and pavements, they must be located below communication routes. Then water is able to flow by lower parts of the curb. This is the simplest form of street drainage (Wagner and Krauze, 2014). This makes also further guidelines for the selection of plants. It should be considered that the plants are exposed to more polluted air and soil nearby the roads, therefore they should be more resistant to pollution and salinity. It is also necessary to choose such plant species so that they do not limit the visibility of the drivers. Therefore it is important what height they can reach depending on their location (Szulc, 2013). Whereas, the plants which tolerate large shading should be selected when it is necessary to design a rain garden near the façade of the building. In addition, it is good that the plants in the rain garden are planted quite dense (about 6 plants per square meter) (Domanowska i Kostecki, 2015).

Benefits. Implementation of green infrastructure at the city or district level, which supports sustainable rainwater management, is a local urban and design strategy that can also contribute to meet the sustainable development and resilience goals (Church, 2015). Rain gardens bring many

* Kontaktinis asmuo / Corresponding author

benefits and the most important ones include the increase of bioretention and infiltration of water to the ground, as well as effective and efficient purification of rainwater from pollutants (Mehring and Levin, 2015; Ishimatsu, Ito et al., 2017; Choi, Maniquiz-Redillas et al., 2018). However, appropriate vegetation must be designed to make rain gardens work as water treatment. As the research conducted by M. Dietz and J. Clausen (2005) indicates, that not every species selection that ensures high bioretention and control of water runoff will ensure adequate water purification.

Rain gardens also contribute to the increase of biodiversity (habitat-forming function) and increase the aesthetic values of the landscape. Furthermore, they reduce the risk of floods, improve water and air quality, increase groundwater recharge, ease water resource shortage and support urban sustainability (Xu, Chen et al., 2015). It is also worth to mention that the costs of maintaining properly designed garden are relatively low and relieve the municipal sewage networks which construction is very expensive (Kosmala, 2003; Choi, Maniquiz-Redillas et al., 2018). There are also researches that are being carried out to estimate the quantity of potential benefits of green stormwater infrastructure depending on its localizations. For such studies, the hydrologic model simulation is being used (Dietrich, 2016).

Good practices. In the United States and Germany, when designing the new green areas on the scale of a district, park or road, a lot of attention is paid to rainwater management with use of thoughtful systems. As a result, all rainwater is precisely collected and then reused. Part of it is intended for irrigation of plants or creating artificial reservoirs, while the rest supply groundwater (Kosmala, 2003). For this purpose, numerous rain gardens are created. They can be found for example in the German housing estates such as Arkadien in Asperg, Küppersbusch in Gelsenkirchen or Kronsberg in Hanover. They are also created in German public spaces, such as the Scharnhauser Park in Ostfildern, Potsdamer Platz and the Mauerpark in Berlin, Wasserspuren in Hann. They are also present in American public spaces such as Tanner Springs Park in Portland or Central Park in New York (Długozima, 2009).

As a result of such projects, it is possible to solve many problems. A good example of this is the *Sidewalk Garden* project in San Francisco, which has been implemented since 2013. It is realized in frames of the larger program – *Urban Watershed Assessment* in the *Sewer System Improvement Program*. The initiators were public agencies, engineering and design companies, non-governmental organizations, experts and the citizens. The idea of the project is to create rain gardens in the place of concrete pavements (Fig. 2). Main aim is to relieve the city's stormwater sewer by capturing rainwater. This is a response to the problem of an increasing number of impervious surfaces within the city and, as a consequence, overloading of traditional gray infrastructure with limited capacity. An additional benefit is the improvement of aesthetic values of public spaces and environmental protection, because of fewer amounts of chemicals that get along with surface runoff to the bay (Galblaub, 2014).

Fig. 2. Space near the Synergy School in San Francisco before (on the left) and after (on the right) the Sidewalk Garden project (www.flickr.com ©Friend of the Urban Forest)

Another noteworthy initiative is the *10,000 rain gardens program*, which is the part of the *Melbourne Water Strategy for Managing Rural and Urban Runoff*. In response to the problem of pollution of the Port Phillip Bay and the Yarra River waters, more than 10 000 rain gardens were

* Kontaktinis asmuo / Corresponding author

built working with the community. The aim was to improve the quality of rainwater, which when running off through the surfaces such as parking lots, roads or roofs, gain a lots of pollution. Moreover this project served as an educational function. The society was being informed about the water cycle and how it can contribute to solve the problem. Thanks to this, gardens were created not only in public areas, but also on private properties (Śmietańska, 2012).

In Poland, designing rain gardens become more popular, but these solutions are still not widely used. A project implemented by the Sendzimir Foundation as part of *the program of sustainable use of surface and rain water* in the city can be discussed as a good practice. In frame of this initiative, many educational events on the subject of water circulation in the city were implemented. Local communities were also involved in the building of rain gardens as part of the workshops. It is worth to notice that the professionals also worked with the youngest residents – children from primary schools. As part of the project, a map of places favoring water retention in Warsaw was also created to increase the awareness of people about such places.

Discussion

Unfortunately, the Polish practice of space management still lacks a comprehensive approach and effective tools for implementing water management objectives. Some single examples of good practices are only a drop in the ocean of needs (Januchta-Szostak, 2014).

Bialystok lacks rain gardens. The intensive development and increasing amount of impervious surfaces in Bialystok city lead to insufficient capacity of the stormwater sewer system during heavy rains. As the result, the streets where water flows are turning into 'rivers' (Fig. 3). Unfortunately, the city authorities do not draw conclusions and new investments, such as modernization or development of road infrastructure, contribute to an even greater reduction of permeable areas. A good example here can be the modernization of Legionowa Street, where during the works even a green belt separating roadways was paved (Fig. 4). Such behavior will certainly not help to solve the problem. However, just leaving the grassy surface would not change much. In case of greater rainfall, also the large water runoff starts to be a problem and of course the lack of places where water can infiltrate into the ground. Even biologically active surface such as lawns cannot stop excessive water especially that the soil in urban areas is heavily compacted. Supporting of the traditional water management by construction of the rain gardens network to make better drainage of water to the stormwater sewer system would be an effective solution (Długozima, 2009; Basdeki, Katsifarakis et al., 2016). This would increase the bioretention and improve infiltration of water to the ground.

Fig. 3. Flooded Legionowa Street (www.poranny.pl)

Fig. 4. Legionowa street after the modernization (www.skyscrapercity.pl ©jacentykasi)

Usually, however, the ecological aspects alone are not enough to convince the public opinion to invest in the development of green infrastructure. Only facts supported by the estimation of high efficiency with

* Kontaktinis asmuo / Corresponding author

relatively low construction costs may prove decisive (Vandermeulena, Verspecht et al., 2015). What is more, rain gardens can purify water and also can provide attractive arrangement of the public space. One of the assumptions of the concept of ecosystem services is that these services also result in financial benefits (indirect and direct). They can be associated, for example, with reducing water consumption for watering urban green areas (Domanowska, Kostecki et al., 2015).

There are many places where green infrastructure can be implemented. It can even enter school areas due to the need to use any surface to reduce the problem of excess rainwater. In the United States traditional spaces full of asphalt surfaces at schools and playgrounds are transformed into green enclaves. According to idea of green infrastructure, a new look of school areas has been created, which thanks to greenery and playing fields can collect rainwater not only from this place, but also from the surrounding housing estates (Połucha, 2013).

Conclusions

Rainwater is needed for the city. Its natural evaporation improves the microclimate and affects on residents in positive way. There is a possibility to use rainwater for economic purposes by city users. It is therefore necessary to change the current procedure. Instead of draining rainwater outside the city, the city should manage it. As a result it will not only improve water relations, but also will bring measurable economic savings (Szuba, 2008). Sustainable stormwater management facilities have also potential in educating society about water cycle in urban areas particularly if they are combined with informational signs. In the long term it will bring measurable environmental benefits (Church, 2015). Although the topic related to the utilizing bioretention for stormwater management is widely described in the literature of the subject, there are gaps in current studies that require further researches, particular in case of areas with cold climate (Kratky, Li et al. 2017).

Note: The article was prepared in frames of the statutory work S/WBiIS/2/2016 realized by KKBiA, WBiIŚ, PB.

List of literature

1. ASLA. (2012). Green Infrastructure, American Society of Landscape Architects. Internet link: https://www.asla.org/ContentDetail.aspx?id=24076
2. Autixier, L., Mailhot, A., Bolduc, S., Madoux-Humery, A. S., Galarneau, M., Prevost, M. & Dornes, S. (2014). Evaluating rain gardens as a method to reduce the impact of sewer overflows in sources of drinking water. *Science of the Total Environment, 499*, 238–247.
3. Basdeki, A., Katsifarakis, L. and Katsifarakis K. L. (2016). Rain gardens as integral parts of urban sewage systems: A case study in Thessaloniki, Greece. *Procedia Engineering, 162*, 426–432.
4. Bogacz, A., Woźniczka, P., Burszta-Adamiak, E. and Kolasińska, K. (2013). Metody zwiększania retencji wodnej na terenach zurbanizowanych. *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska, Vol. 22, 1*(59), 27-35.
5. Burszta-Adamiak, E. (2012). Wody opadowe w miastach. *Rynek Instalacyjny, 5*, 35.
6. Choi, J., Maniquiz-Redillas, M. C., Hong, J., Kim, L.-H. (2018). Selection of cost-effective Green Stormwater Infrastructure (GSI) Applicable in Highly Impervious Urban Catchments. KSCE Journal of Civil Engineering, nr *22*(1), Springer, , pp. 24–30.
7. Church S. P. (2015). Exploring Green Streets and rain gardens as instances of small scale nature and environmental learning tools. *Landscape and Urban Planning, 134*, 229–240.
8. Dietrich, A., Yarlagadda, R. and Grudena, C. (2017). Estimating the Potential Benefits of Green Stormwater Infrastructure on Developed Sites Using Hydrologic Model Simulation. *Environmental Progress & Sustainable Energy, 36*(2), 557–564.
9. Dietz, M. E. and Clausen, J. C. (2005). A Field evaluation of rain garden flow and pollutant treatment. *Water, Air, and Soil Pollution, 167*, 123–138.
10. Długozima, A. (2009). Ogrody deszczowe. *Problemy Ekologii, 13*(4), 211-215.
11. Domanowska, M. and Kostecki, J. (2015). Ogrody deszczowe w miastach jako jedno z narzędzi wdrażania usług ekosystemów: Inżynieria środowiska. *Zeszyty naukowe, 158*(38), 50-58.
12. Federal Interagency Stream Restoration Working Group. (1998). Stream corridor restoration: Principles, processes, and practice, P. 3–23. Internet link:

* Kontaktinis asmuo / Corresponding author

http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf
13. Galblaub, O. (2014). Przyuliczne ogrody. *Zrównoważony Rozwój – Zastosowania,* 5, 121. Fundacja Sendzimira, Kraków.
14. Ishimatsu, K., Ito, K., Mitani, Y and Naka, Y. (2017). Use of rain gardens for stormwater management in urban design and planning. *Landscape and Ecological Engineering, 13*, 205–212.
15. Januchta-Szostak, A. (2014). Rola urbanistyki i architektury w gospodarowaniu wodą. *Woda w mieście. Zrównoważony Rozwój – Zastosowania, 5*, 31-47. Fundacja Sendzimira, Kraków.
16. Katsifarakis, K. L., Vafeiadis, M. and Theodossiou. (2015). Sustainable Drainage and Urban Landscape Upgrading Using Rain Gardens. Site Selection in Thessaloniki, Greece. *Agriculture and Agricultural Science Procedia, 4*, 338–347.
17. Kosmala, M. (2003). "Ogrody deszczowe" czyli ogrody retencjonujące wody opadowe – moda czy konieczność: Woda w przestrzeni przyrodniczej i kulturowej. *Prace komisji krajobrazu kulturowego, 2*, 265-274.
18. Kozłowska, E. (2008). *Proekologiczne gospodarowanie wodą opadową w aspekcie architektury krajobrazu*. Wrocław: Wydawnictwo uniwersytetu przyrodniczego we Wrocławiu, p. 21, 27.
19. Kratky, H., Li, Z., Chen, Y., Wang Ch., Li X. and Yu T. (2017). A critical literature review of bioretention research for stormwater management in cold climate and future research recommendations. *Frontiers in Earth Science, 11*(4), 2-15.
20. Mehring, A. S. and Levin, L. A. (2015). Potential roles of soil fauna in improving the efficiency of rain gardens used as natural stormwater treatment systems. *Journal of Applied Ecology, 52*, 1445–1454.
21. Połucha, J. (2013). Projektowanie terenów szkolnych i placów zabaw jako zielonej infrastruktury. *Problemy ekologii krajobrazu, XXXVI*, 61-71.
22. Śmietańska, M. (2012). Program 10 000 ogrodów deszczowych? *Zrównoważony Rozwój – Zastosowania,* 3, 121. Fundacja Sendzimira.
23. Stawicka, J. (2010). Ogrodowe rabaty synantropijne. In *Wzornictwo ogrodowe, Rylke J. (ed.)*, 97–106.
24. Szuba, B. (2008). Racjonalne gospodarowanie wodą deszczową w mieście. *Problemy Ekologii, 12*(3), 134-139.
25. Szulc, A. (2013). *Zielone Miasto: Zieleń przy Ulicach*. Warszawa: Agencja Promocji Zieleni, pp. 25-30, 34-36, 91-92.
26. Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G. and Gellynck, X. (2011). The use of economic valuation to create public support for green infrastructure investments in urban areas. *Landscape and Urban Planning, 103*, 198-206.
27. Wagner, I. and Krauze, K. (2014). Jak bezpiecznie zatrzymać wodę opadową w mieście? Narzędzia techniczne. *Zrównoważony Rozwój – Zastosowania, 5*, 75-93. Fundacja Sendzimira, Kraków.
28. Wagner, I., Krauze, K. and Zalewski M. (2013). Błękitne aspekty zielonej infrastruktury. *Zrównoważony Rozwój – Zastosowania, nr 4*, 145-155. Fundacja Sendzimira, Kraków.
29. Wagner, I., Krauze, K., Jurczak, T. and Zalewski, M. (2015). Zielono-błękitna infrastruktura a retencja krajobrazowa w miastach. *Wodociągi-Kanalizacja, 9*(129), 22-25. Abrys, Poznań.
30. Xu, H., Chen, L., Zhao, B., Zhang, Q. and Cai, Y. (2015). Green stormwater infrastructure eco-planning and development on the regional scale: a case study of Shanghai Lingang New City, East China. *Frontiers in Earth Science, 10*(2), 366–377.

Направленный сток воды – зеленая поддержка городской ливневой инфраструктуре

(Получено в январе 2018 г.; отдано в печать в апреле 2018 г.; доступ в интернете с 8 мая 2018 г.)

Резюме

Основываясь на польской и зарубежной литературе, были охарактеризованы вопросы, связанные с зеленой инфраструктурой, а в частности с направленным стоком воды. В то же время были затронуты экологические и экономические темы, а также обнаружена проблема новых инвестиций на примере города Белостока.

Игнорирование правил равномерного развития при постоянном развитии городов приводит к многочисленным проблемам, в том числе к неверному распределению сточных вод. При территориальном планировании польских городов значительно большее внимание уделяется на эффективный отвод сточных вод из городов посредством обширных канализационных систем. Излишние сточные воды сбрасываются в реки или водоемы без предварительной очистки, что негативно влияет на экологию.

Зеленая инфраструктура городов является одной из концепций равномерного территориального планирования, которая включает в себя направленный сток воды, предназначенный для увеличения ретенции воды и впитывания ее в грунт. С этой целью проектируются специально подобранные растения в небольших углублениях на прилегающей территории. Особое внимание уделяется использованию местных видов

* Kontaktinis asmuo / Corresponding author

растений. Такой подход к проектированию обладает множеством преимуществ. В высокоразвитых странах, таких как США, Германия или Австралия, можно заметить множество примеров применения подобных практик, которые должны применяться и в Польше, однако пример города Белостока показывает, что новые инвестиции по-прежнему не учитывают развитие зеленой инфраструктуры.

Современные города все больше нуждаются в соответствующем управлении сточными водами. Это принесет ощутимую выгоду в экономических и экологических аспектах, а также поспособствует увеличению осведомленности жителей о циркуляции воды в природе.

* Kontaktinis asmuo / Corresponding author