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Application of green infrastructure for pollutant removal from stormwater

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ABSTRACT:
Stormwater runoff is a source of water pollution containing a wide range of chemical pollutants and various disease-causing bacteria and viruses that are transported by runoff to water bodies and have a negative impact on aquatic ecosystems. Therefore, stormwater treatment should meet the highest standards and contribute to sustainable water resource management. Responding to today‘s environmental challenges and following the Green Deal and Circular Economy's goals, it is necessary to apply new innovative solutions and infrastructure in stormwater management. Research shows that green solutions might be a potential tool to treat stormwater and to ensure the proper quality of surface water bodies. The article aims to discuss various possible solutions of green infrastructure (rain gardens, green roof, wetlands etc.), which could be applied in future research to remove pollutants (heavy metals, organic compounds etc.) from stormwater. Studies have found multiple benefits of using green infrastructure in order to protect the environment. It is a cost effective, innovative and architectural measure, which promotes economic growth, contributes to climate change mitigation, reduces urbanization impact on the environment and creates recreational and green spaces.

KEYWORDS:
green infrastructure; water pollution; decontamination; ecosystems; wetlands

1. Introduction

The United Nations foresees that about 4.8-5.7 billion people will face water shortages in 2050. It is an increasing problem showing that in the near future human health, the environment and sustainable development will completely depend on freshwater resources [1]. The sixth goal of the Agenda 2030 on Sustainable development declares the importance of sustainable water management, also access to water and sanitation for all [2]. This has encouraged countries to search for new ways of efficient water management [3].

Research show that surface water is mostly effected by chemical substances transported by runoff from urbanized areas. Hazardous compounds, such as heavy metals, organic matters and biocides may cause a negative impact on rivers and lakes, as well as deteriorate water quality. Various substances (metals, organic compounds, nutrients) carried by stormwater have a strong ecotoxic impact [4]. Copper, iron, zinc, selenium, lead, manganese, arsenic, nickel and cadmium are heavy metals mainly found in stormwater. Depending on the urbanized area, various concentrations of other substances like organic compounds, biocides, etc can also be detected [5]. Therefore, stormwater treatment should meet the highest environmental and health requirements. Proper stormwater decontamination contributes to sustainable water resource management and

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reduces the load on sewage systems [6]. What is more, the use of innovative treatment technologies allows the collection and reuse of stormwater. Today's challenges call for the design and development of smart green infrastructure. Innovative technologies and nature based solutions might be the key factor in order to protect surface water bodies from the negative effects of environment pollution and remove hazardous substances from stormwater before they enter rivers or lakes.

Fig. 1. Green Building in The Botanical Garden, Vilnius, Lithuania

Green roof constructions, wetlands, rain gardens, wetwalls, biological decomposition, photocatalytic processes and adsorption are mainly applied to reduce stormwater pollution and decontaminate hazardous compounds [7]. Green solutions could be considered as the main factors of sustainability, contributing to efficient stormwater management and climate change mitigation, as well as to the decreased impact of urbanization and may also solve social, economic and environmental issues (Fig. 1). The European Commission defines green infrastructure as an effective tool for achieving environmental, economic and social benefits through natural solutions [8]. It could be successfully applied to stormwater management due to the ability of natural vegetation and soil to retain and adsorb pollutants. The use of natural coagulants and recycled materials instead chemical substances has already become the key tool in stormwater treatment processes [9, 10]. Research shows an approximately 66 percent efficiency of natural sorbents (hemp fiber) in removing chlorine based compounds from stormwater [11].

2. Analysis of green infrastructure

Green infrastructure (GI) is an effective alternative compared with traditional methods of stormwater treatment. It includes the collection and reuse of stormwater, using different plants and soils, permeable pavements and substrates as well as the process of infiltration, evaporation and storage of stormwater in order to reduce loads on sewage systems and water bodies. GI can provide a clean environment, ensure flood protection and create green spaces for communities. Examples of GI solutions are the following: green roofs, rain gardens, wetlands, wetwalls, panter boxes, bioswales, green streets, etc. Nowadays, green roofs are considered an innovative, architectural trend and smart solution to reducing environmental pollution. Green roofs retain pollutants and protect water ecosystems and are widely used in the following countries: Germany, Sweden, USA, Japan and Singapore. Experimental research shows that about 41 chemical elements (heavy metals, biocidal products, etc.) enter the environment during precipitation. Green roofs reduce pollution by absorbing pollutants using plant substrate and soil [12] while decreasing the load on the sewage systems [13]. In order to retain hazardous elements and protect water quality, green roof constructions are constructed in urban areas. Green roof runoff quality depends on the following factors: soil type and composition, thickness of the base layer, as well as the type of drainage and filler material. Green elements presented in roof construction absorb pollutants present in stormwater [14]. They also purify the air, save energy and encourage biodiversity in the cities. They are economical and ecological tool for stormwater treatment [15]. Researchers [16] proposed the application of floating wetlands for stormwater treatment. Floating wetlands are artificial systems that simulate stormwater treatment processes [17].

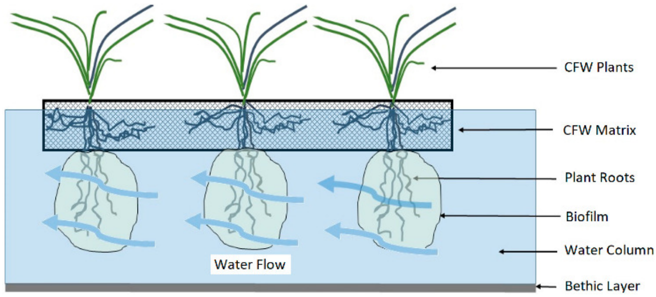

Fig. 2. Construction of floating wetlands [17]

They consist of a floating structure containing plants whose roots grow into the water column (Fig. 2). A biofilm fixed to the roots area adsorbs pollutants through filtration and by containing suspended solids. Studies have shown that this technology can be used to reduce pollution in urban areas caused by stormwater runoff. Rain gardens are another effective stormwater treatment technology that protects water bodies from pollutants [18]. These are shallow depressions covered by green plants, soil and a layer of mulch. The plants and soil absorb stormwater and remove hazardous substances (heavy metals, organic, biocidal substances, etc.) by filtration, adsorption and evaporation. Rain gardens are an economical method to reduce stormwater pollution and improve the landscape and add to the aesthetic image of cities. Rain gardens are an advanced green technology that treats pollutants in stormwater using various methods (adsorption, reduction, sedimentation, etc.) [18]. Research reveals that Rain gardens require maintance work to protect infrastructure from waste and other substances which can enter the sewage system through runoff during rain as well as to take care of plants in order to remove various weeds and overgrown plants [19].

3. Design of green infrastructure

The installation of green infrastructure is closely related to stormwater management. However, it can also provide a liveable and green environment for communities. Green infrastructure (GI) solutions are implemented by the requirements of different types of GI construction: green roofs, wetlands, rain gardens, etc. GI constructions consist of the following layers: waterproofing, drainage, geomembrane, substrate and vegetation cover (Fig. 3) [20].

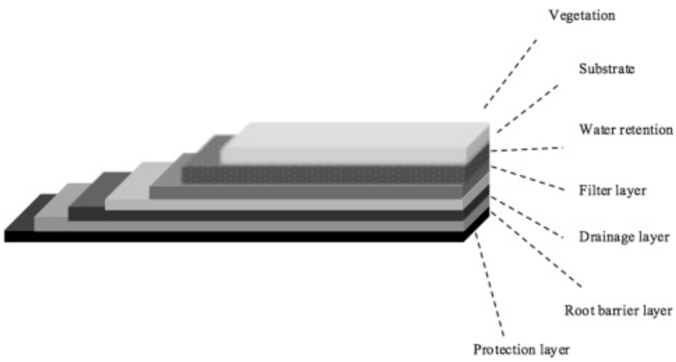

Fig. 3. Layers of green roof construction [20]

The efficiency of green construction depends on substrate type, thickness of the base layer, type of drainage and also the filling material. Studies show that the materials used in green construction can also be the source of hazarous pollutants. Therefore is very important to select the proper materials. The following research analysed the impact of reactive drainage fillings on the quality of stormwater from landscaped structures [21]. The research also included an investigation into micro and macro pollutants (for instance aluminium, calcium, magnesium, potassium, sodium, strontium, titanium and zinc, etc.) present in the filtrate materials (crushed bricks, clay pellets, sewage sludge, ash, etc.). The study used various fillers commonly applied as a drainage layer in green construction and also reactive materials applied as a possible drainage medium. The efficiency of pollutant removal depended on the soil filtration properties and of the plants' ability to absorb pollutants. Inexpensive and recycled adsorbents are usually used in pollutant treatment processes in order to contribute to sustainable stormwater management [22], for instance, wood mulch. Studies show that mulch is used in green infrastructure as a protective layer to control soil moisture and protect the soil from weeds [23]. Fillers used in green infrastructure should be selected using these characteristics: granulometric composition, frost resistance, water permeability and water capacity, structure and layer stability, behavior under compressive loads, pH value and salt content.

Research shows that there three different installation direction possibilities in GI: upstream, sidestream and downstream. The correct position for the specific GI depends on runoff direction [24]. It is found that GI decreases the load of discharged pollutants by 40-68 percent. The efficiency of stormwater treatment depends also on the location of the GI installation. Research determined that the downstream construction removes 10-44 percent of pollutants and is more efficient than than the sidestream or upstream constructions [25].

GI efficiency depends also on these parameters: vegetation cover, soil texture and surface roughness. GI vegetative cover and soil texture is important because of their capture and filtration of runoff and their pollutant retention [25]. Studies revealed that plants remove hazardous substances by phytoremediation breaking down or accumulating pollutants in their roots, stems or leaves. The research shows that vegetation cover and soil are important elements for phytoremediation efficiency. Therefore is important to select proper plant species according their physiological properties and symbiosis with microorganisms. The success of phytoremediation should also be determined by the following parameters: oxygen and nutrient concentration, temperature, pH and other abiotic factors. Studies showed that the removal of organic pollutants from stormwater was 56.56% and 50.25% by phytoremedaition processes [26]. The surface roughness also impacts the runoff route and pollutants removal. All these parameters should be evaluated when designing green infrastructure and achieving sustainable stormwater treatment goals as well as improving surfaces water quality.

4. Conclusions

The conducted research drew the following conclusions:

1. In order to contribute towards the Green Deal, Circular Economy and Agenda 2030 goals and to ensure sustainable stormwater management, it is recommended to apply green solutions to protect surface water bodies. Nature based solutions might be the key factor in order to remove hazardous substances from stormwater before they enter rivers or lakes.
2. Green solutions contribute to efficient stormwater management and climate change mitigation, as well as decrease the urbanization impact and support social, economic and environmental development.
3. The efficiency of green constructions depend on substrate type, thickness of the base layer, type of drainage and filler material. Studies show that the materials used in green roof construction can also be the source of hazarous pollutants. Therefore is very important to select the proper materials.
4. It was found that green infrastructure decreases the load of disharged pollutant by 40-68 percent. The efficiency of stormwater treatment depends on the location of GI installation.

Research determined that downstream installed constructions remove up to 44 percent of pollutants and are more efficient than sidestream or upstream installed constructions.

5. Future research will be dedicated to chlorine affected water reuse by urban gardening.

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Zastosowanie zielonej infrastruktury do usuwania zanieczyszczeń z wód opadowych

STRESZCZENIE:

Spływ wód opadowych jest źródłem zanieczyszczenia wody zawierającego szeroką gamę substancji chemicznych oraz różne bakterie i wirusy chorobotwórcze, które wraz ze spływem przenoszone są do zbiorników wodnych i mają negatywny wpływ na ekosystemy wodne. W związku z tym oczyszczanie wód opadowych powinno spełniać najwyższe standardy i przyczyniać się do zrównoważonego zarządzania zasobami wodnymi. Odpowiadając na współczesne wyzwania środowiskowe oraz kierując się celami Zielonego Ładu i Gospodarki o Obiegu Zamkniętym, konieczne jest stosowanie innowacyjnych rozwiązań i infrastruktury w zarządzaniu wodami opadowymi. Badania pokazują, że zielone rozwiązania mogą być potencjalnym narzędziem oczyszczania wód opadowych i zapewnienia odpowiedniej jakości części jednolitych wód powierzchniowych. Celem artykułu jest omówienie różnych możliwych rozwiązań zielonej infrastruktury (ogrody deszczowe, zielone dachy, tereny podmokłe itp.), które można zastosować w przyszłych badaniach nad usuwaniem zanieczyszczeń (metali ciężkich, związków organicznych itp.) z wód opadowych. Badania wykazały wiele korzyści wynikających z wykorzystania zielonej infrastruktury w celu ochrony środowiska. Jest to rozwiązanie opłacalne, innowacyjne i architektoniczne, które sprzyja wzrostowi gospodarczemu, przyczynia się do łagodzenia zmian klimatycznych, zmniejsza wpływ urbanizacji na środowisko oraz tworzy przestrzenie rekreacyjne i zielone.

SŁOWA KLUCZOWE:

zielona infrastruktura; zanieczyszczenie wody; odkażenie; ekosystemy; tereny podmokłe