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CIRCULAR ECONOMY IN WATER MANAGEMENT

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INTRODUCTION

Circular economy in water management involves several key elements, including water efficiency and conservation, wastewater treatment and reuse, rainwater harvesting, and recycling of waste generated after wastewater treatment. The goal of this approach is to create a closed-loop system where water is seen as a valuable resource and is managed in a manner that minimizes waste, optimizes its use, and protects the natural environment. Adopting a circular economy approach to water management can help to conserve water resources, reduce the impact of water pollution, increase water security, and improve the sustainability of communities. However, implementing this approach requires significant investments in infrastructure, technology, and human capital, as well as a change in consumer behavior and a shift towards a more sustainable and resource-efficient water management system.

Wastewater treatment is a process that involves cleaning used water and making it suitable for reuse in various applications. Gray water is wastewater generated from household activities such as bathing, laundry and dishwashing and other similar activities. Unlike black water, which comes from toilets and contains faeces, gray water is less polluted and can be treated and reused for various purposes. The wastewater is treated using various physical, chemical, and biological methods to remove contaminants and pathogens, resulting in the production of treated wastewater, white water. The treated water can then be used for irrigation, industrial processes, and other non-potable purposes, thus reducing the demand for potable water.

Biochar is a by-product after thermal treatment of biomass and biosolids that can be used in blue-green infrastructure of cities as a soil amendment to improve soil health and increase the growth of vegetation. Biochar also has the ability to retain nutrients, water and suppress pathogens, thus improving the overall soil quality and promoting the growth of vegetation. Additionally, the use of biochar in urban green spaces has been shown to reduce the amount of carbon dioxide (CO_2) in the atmosphere, thus contributing to the reduction of greenhouse gas emissions. The use of biochar in urban agriculture and landscaping can help create sustainable and resilient green spaces, which are essential for the health and well-being of urban residents.

Thermal treatment of biomass and biosolids refers to the process of using heat to convert organic waste materials into useful products (biochar, bio-oil, and bio-gas). Biomass includes plant materials such as wood, agricultural waste, and municipal solid waste, while biosolids are the organic material that results from the treatment of wastewater.

WASTEWATER TREATMENT

Sustainable water management is a globally significant environmental, economic and energy solution to the continuing demand for water and energy resources caused by climate change, population growth and rapid urbanization. In this case, the separation and recycling of wastewater already at the level of households and other residential or commercial buildings could be considered as a key result of modern conceptual developments concerning the perception of waste as a resource. The reuse of less polluted gray water, which is an important component of wastewater, can play a crucial role in transforming wastewater into a valuable water resource. All water that undergoes a manufacturing process or other use that compromises its quality is considered wastewater. In common practice, wastewater is discharged from the point of generation, from households, into a balancing pit or via a sewer connection to a domestic sewage treatment plant or a sewer system, from where it is further discharged to a treatment site, a sewage treatment plant, and then discharged into a water body.

Wastewater can be divided into three types according to the point of generation:

- **black wastewater**: water from toilets, urinals, containing faecal pollution;
- **gray wastewater**: wastewater from bathing, hand washing, kitchen sink, laundry, clean industrial water, wastewater usually not containing faecal pollution;
- **rainwater**: rainfall, rainwater from roofs of buildings and paved areas.

Relatively clean gray water in large volumes is produced in facilities such as hotels, schools, restaurants, hostels, office buildings, university buildings and other facilities. White water can be used for flushing toilets, irrigating gardens and lawns, or used for other needs of the population, e.g. house cleaning, or for technological or operational purposes. An example of a large source of gray water could be laundries, i.e., operations with a large production of gray water and a large need for white water.

The main concern with white water recovery may be the potential risk to the health of users or operators of the gray water recovery system. For these reasons, regulations and standards are mainly based on the monitoring of microbiological indicators. These include monitoring for Escherichia coli, enterococci, Legionella pneumophila, total coliforms, etc. In addition to this microbiological contamination, it is also important to monitor the appearance and quality of the treated water itself. Other parameters monitored include biochemical oxygen demand BOD_5, chemical oxygen demand COD, suspended solids, turbidity, etc. In the case of the use of gray water from kitchen sinks and dishwashers, gray water with a high content of BOD_5, floatables, lipids and tensides is fed to the treatment systems. Removing this type of pollution is economically costly.

<u>The gray water recovery systems divide according to the treatment process:</u>

- **simple treatment** (mechanical pre-cleaning and disinfection of the system);
- **chemical treatment** (photocatalysis, electrocoagulation and coagulation);
- **physical treatment** (sand filter, adsorption and membranes);
- **biological treatment** (biological aerated filters, rotating contact bioreactor and membrane bioreactor);
- **natural treatment practices** (wetlands, root treatment plants, reed fields).

Most of these treatment technologies are operated at the beginning of the treatment process with sedimentation, the end part is usually a sanitary gray water recovery system. To disinfect the treated gray water, UV radiation or ozone can be included. The most commonly used gray water treatment technology is biological treatment, followed by physical treatment and natural treatment processes. The most attractive approach for on-site treatment of gray water is physical, specifically the use of the membrane process, mainly due to the quality of the permeate, white water, low space requirements and ease of operation.

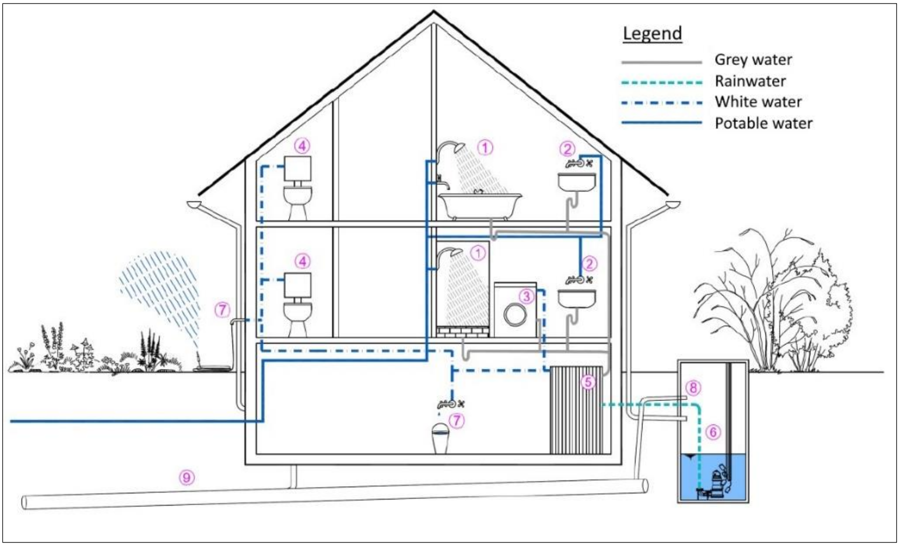

Figure 1. Water cycle in the building (1–shower, 2–sink, 3–washing machine, 4–toilet, 5–gray and rainwater treatment unit, 6–tank for rainwater, 7–white water collection, 8–security overflow, 9–sewer connection)

THERMAL TREATMENT OF BIOMASS

Generally, the term waste with organic content can also be defined as biomass, when the biological material is derived from the original plant or animal waste. Waste biomass from agriculture can be called agromass. Another example is biomass derived from wood processing industry, the food industry, from municipal waste and sludge management from wastewater treatment plant in the form of thickened, dewatered or dried sewage sludge. At the present, circular economy strategy of wastewater management postulates a search for new ways of reusing sewage sludge, among them thermal treatment is one of the most promising approaches. Generally, thermal treatment, such as incineration, gasification, hydrothermal carbonation and pyrolysis belong among the suitable solutions of sewage sludge disposal. Two different ways exist, the first one is burning of sewage sludge for energy production and the second one is the transformation of sewage sludge into a new product for agricultural use or use in blue-green infrastructure of cities. The second way is a challenge in research focusing on the pyrolysis products, especially biochar. Biochar may represent the main product of pyrolysis of sewage sludge, which can be consequently one of the most significant application in wastewater management and consequent use in agricultural and blue-green infrastructure.

In general, there exist many thermochemical treatment processes, which can be classified into two main categories such as thermochemical oxidative processes and thermochemical reductive processes. Thermochemical oxidative treatment processes include combustion in which oxygen is present in stoichiometric or larger amounts. Thermochemical reductive processes include gasification, hydrothermal carbonization and pyrolysis, in which oxygen is absent or the amount of oxygen is subtechiometric.

Figure 2. Pelletized (6 mm) dried sewage sludge with wooden sawdust (left), biochar from dried sewage sludge with wooden sawdust (right)

Figure 3. Thermal pyrolysis unit at AdMaS Research Centre

Pyrolysis is the thermochemical reductive process of converting biosolids into carbon rich solid product (biochar), having yield above 10–80% carried out under a wide temperature range 100–1300 °C, at wide residence time 0.05 s–12 h under low or atmospheric pressure. The other products of pyrolysis are pyrolysis oil, thus bio-oil mixed with water, and pyrolysis gas, sometimes called syngas. Pyrolysis gas mainly contains CO, CO_2, CH_4 and H_2.

Gasification is the thermochemical reductive treatment process of converting biosolids into gas (synthetic gas called syngas) with the yield above 85% at high temperatures 800–1200 °C, short residence time 10–20 s and without oxygen. The combustible syngas contains predominantly H_2, CO, CH_4 and CO_2 mixture. The byproducts of gasification are bio-oil and biochar, but their yields are low.

Hydrothermal carbonization is the thermochemical reductive treatment process of converting biosolids. It represents an alternative to slow pyrolysis of biosolids. Hydrothermal carbonization converts biosolids into solid char (hydrochar) with the yield above 45–75% at 175–295 °C. During the thermal treatment, biosolids is submerged in water and heated in a confined system under 2–6 MPa pressure with residence time 5–240 min. The by-products of hydrothermal carbonization are liquid products, such as biooil mixed with water, and small fractions of gas products, mainly CO_2.

BLUE-GREEEN INFRASTRUCTURE

In urbanized areas, rainwater does not return unaffected to the natural water cycle. This leads to a gradual change of underground water with a structural change in soil properties in urbanized areas, which is also related to the change of chemical and biological processes in the soil environment. In extreme rainwater leads to local flooding caused by the insufficient capacity of the sewage system and water streams. Thus, rainwater in urban areas has the impact on the pollution of watercourses due to the outfalls of the sewage system and the wastewater treatment plants.

The concept of nature-friendly rainwater management in urbanized areas represent designs corresponding to natural rainwater drainage before urbanization. Generally, rainwater management is a decentralized drainage system that is characterized by rainwater at the point of natural production and its use in the natural water cycle. Therefore, acceptable solutions for rainwater management are evaporation, infiltration, and regulated runoff to watercourses. These solutions can be implemented as the accumulation of rainwater and its use for irrigation and flushing toilets. Another implementation of rainwater is retention and slow, regulated drainage into a watercourse or in limited cases into the sewage system. It is necessary to separate the low polluted and high polluted rainwater. Low polluted rainwater is usually from roofs, car parks, and unfrequented roads. High polluted rainwater requires pretreatment in the local treatment system or connection to the sewage system and subsequent treatment in the wastewater treatment plant.

Figure 4. Experimental green roof amended with biochar

At present, rainwater in urbanized areas hardly finds an unaffected path to reach the natural water cycle. In an anthropogenically intact country, up to 99% of rainwater gets infiltrated, and its absorbed by plants or evaporates. The natural water cycle has changed due to the buildings and roads associated with the growing population. Moreover, the change also occurred due to agricultural and forest management. Paved areas such as roads, pavements, and urbanized areas prevent natural water infiltration into the native soils and thus adversely affects groundwater replenishment. Rainwater is polluted by substances from paved areas and thus represents relatively high pollution. With the increasing amount of paved surfaces also the surface runoff increases while the value of groundwater recharge decreases. These situations cause extreme differences between excessive flood flows and drying watercourses which leads to flooding, erosion, water pollution, and reducing the groundwater level.

Biochar made from biomass and biosolids can be used in substrates suitable for urban green infrastructure, especially green roofs, green parking lots, and green walls. Applications of biochar in the soil of green infrastructure systems improve the soil properties. Biochar improves physical (e.g., water holding capacity, greenhouse gases removal and moisture level), chemical (e.g., pollutants immobilization and carbon sequestration), and biological (e.g., nutrients, microbial abundance, and diversity) properties of the soils. The green infrastructure concept leads to a reduction in the temperature in buildings during summer (green roofs and walls) and reduces the energy needs for cooling buildings, thus improving the microclimate in cities. The green infrastructure concept will capture rainfall and reduce surface runoff into the sewer, nutrients in biochar (N, P, C, K) will be used in the green infrastructure and the idea of "waste to product" will be implemented. In the case of green parking lots, traffic pollution (petrol, oil) will be reduced by adsorption on the biochar.

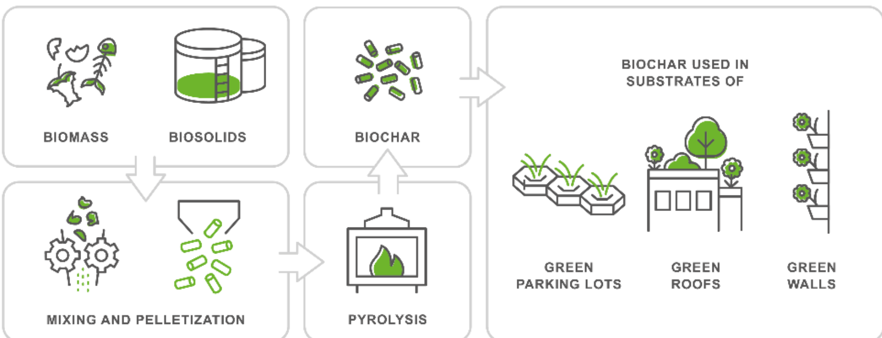

Figure 5. Scheme of biochar production and use in green infrastructure

EXPERIMENTAL GREEN ROOFS IN BANJA LUKA

Green roofs have great potential for managing urban runoff. However, the effects of green roofs on the quality of infiltrating water are highly variable. Unfortunately, in some cases, green roofs may contain high concentrations of nutrient pollutants and heavy metals. In this project, seven types of experimental modules were established in August 2022 in open space near the laboratories in campus faculty of agriculture. The effect of a substrate supplemented with biochar and other organic materials on pollution load was analyzed in water runoff for six green roof modules by simulating an artificial rainfall.

Figure 6. Experimental green roof modules in Banja Luka

The technical solution concerns a substrate for green roofs with a proportion of recycled aggregate and a pyrolyzed stabilised product. The main components of the substrate are sorted construction recycle based on brick rubble, which serves as an inorganic, partially water-resistant component of the substrate, and biochar, which represents a stable organic component of the substrate. In addition to these components, the substrate contains other conventional organic and inorganic components such as expanded clay, spongilite, and peat. The organic component of the substrate is different in each module and includes wood biochar, biochar from sewage sludge, biochar from gastro waste, dried sewage sludge, and compost containing sewage sludge.

EXPERIMENTAL GREEN PARKING LOTS AT ADMAS RESEARCH CENTRE

Concrete paved surfaces excessively heat cities and do not allow natural rainwater infiltration. Infiltration gratings are a comprehensive solution to provide a traffic function while also maintaining the original runoff conditions and other environmental aspects. The use of grates with grassing is suitable for average traffic volumes and vegetation loads, e.g. not very busy lanes and parking areas. Paved grates are intended for high traffic and load intensities, e.g. roads with mobile traffic, heavily trafficked lanes and parking lots.

Figure 7. Experimental green parking lots at AdMaS Research Centre

One of the innovative elements in the construction of the experimental polygon is the use of biochar in the construction layer of parking lots. Biochar contributes to the removal of pollutants such as heavy metals, pesticides, organic matter, etc. The paved areas are designed to ensure the load bearing requirements of the green parking lot structural layers with respect to the permeability of rainwater to the subgrade.

<u>The construction layers consist of:</u>

- mixture of **gravel, soil,** and **biochar;**
- mixture of **gravel** and **soil;**
- **gravel.**

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ISBN: 978-80-86020-96-9

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Financing of the publication

- Publication was funded through the project No. 22-PKVV-001 “Use of biochar as materially transformed waste for extensive green roofs” supported by the Ministry of Foreign Affairs of the Czech Republic - Department of Development Cooperation and Humanitarian Aid.

Ministry of Foreign Affairs
of the Czech Republic