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April 22-24, 2024

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Water and Wastewater in the Circular Economy

CEwater

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Division of Biogenic Raw Materials

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waterCEmanagement in practice

developing comprehensive solutions for water reuse and raising awareness of the key role of water in the transformation process towards a circular economy (CE)

The main aim of the project „*Water-CE-management in practice – developing comprehensive solutions for water recovery and raising awareness of the key role of water in the transformation process towards a circular economy (CE)*" is to strengthen the transformation towards a circular economy (CE) in terms of circular management of water resources.

The project activities included a development of water recovery technology from wastewater and rainwater that is introduced by an industrial project partner. Moreover, the project targeted relatively low public awareness of circular and sustainable water management by a dedicated social information-educational campaign to popularise good practices of water recovery and building social acceptance for secondary water sources for household and industrial use.

Project Partners:

- Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (MEERI) – Project Coordinator, Website: https://min-pan.krakow.pl/psb
- Aquateam COWI AS, Website: https://aquateamcowi.no/
- GreenBack Sp. z o. o., Website: http://www.greenback.net.pl/
- Optimus Foundation.

The project "*waterCEmanagement in practices*" uses funding worth 323 549,34 euro received from Iceland, Liechtenstein and Norway under the EEA Funds. The aim of the project is to strengthen the transformation towards a circular economy in the field of circular water resources management. More information on the website of the financing entity: EOG: www.eeagrants.org / www.norwaygrants.org.

Project Webpage: http://www.wodogozowanie.com
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Division of Biogenic Raw Materials

Mineral and Energy Economy Research Institute
Polish Academy of Sciences

Division of Biogenic Raw Materials conducts research in the field of environmental management and engineering as well as biotechnology. The special interest is dedicated to the Circular Economy (CE) model and the Green Deal Strategies in food, water and raw materials sectors.

Division of Biogenic Raw Materials specialises in the analysis and assessment of specific problems and phenomena related to the management of fertiliser raw materials, with particular emphasis on phosphorus, nitrogen and potassium. A special area of interest are issues related to sustainable and circular management of the raw materials in order to optimise the use of resources at the local, regional, national and international levels.

The division's work includes:

- development of recommendations (road maps) for sustainable and circular management of biogenic raw materials;
- recovery of raw materials from waste, including phosphorus from waste generated in the water and sewage sector (fertilisers from waste);
- water in a circular economy and water footprint;
- assessment of technological, legal, environmental and social aspects of biogenic raw materials management;
- strategies for water protection against pollution with biogenic raw materials from anthropogenic sources and determination of directions for counteracting eutrophication;
- analysis of new materials (including nanomaterials) used in municipal and industrial sewage and soil treatment processes.

Division of Biogenic Raw Materials participates in international projects (Horizon 2020, Horizon Europe; EIT Raw Materials, NAWA, Visegrad Fund, Norway Grants) related to the management of phosphorus raw materials and the development of recommendations (roadmaps) for the management of raw materials in the context of implementing the assumptions of sustainable development (SD), circular economy and the European Green Deal in the water and sewage, fertiliser and agri-food sectors.

Division's Website: https://min-pan.krakow.pl/psb

Abstracts

Contents

Introduction

Implementation of circular economy (CE) in the water and sewage sector is supported by national and international funds intended for the implementation of scientific and technical projects in this area. One example is the international project entitled "*Water-CE-management in practice – developing comprehensive solutions for water recovery and raising awareness of the key role of water in the transformation process towards a circular economy*", which aims to strengthen the transformation towards CE in the field of circular management of water resources in Poland. The project was implemented in the period from March 1, 2022 to April 30, 2024 by four partners: Mineral and Energy Economy Research Institute of the Polish Academy of Sciences – project leader (Poland), Aquateam COWI AS (Norway), GreenBack (Poland) and Optimus Foundation (Poland). The project achieved impressive results, such as the development of an innovative method for recovering water from sewage and rainwater, which was implemented in the project partner company. Moreover, an integral element of the project was the development and implementation of a nationwide information and educational campaign, addressed to three groups of recipients: *i*) children, youth and the general public, *ii*) students, PhD students and scientists, *iii*) domestic entrepreneurs operating in various industries and specialists in the water sector. The aim of the campaign was to popularise good water recovery and reuse practices, and build social acceptance for solutions for water recovery from sewage and other waste sources, as rainwater. As part of the information and educational campaign, onsite and online events were organised, including workshops, seminars, trainings, summer school, webinars and competitions for the best CE practices in the water and sewage management sector. In total, several hundred people were trained to improve their water management practices. Knowledge in the field of circular water management should be further popularised, both in homes and in enterprises, to strengthen the transformation towards CE in Poland and abroad.

As a part of ecucation campaign the International Conference “Water and Sewage in the Circular Economy Model” (CEwater) is organised. The aim of this CEwater Conference is to summarise the project *waterCEmanagement in practice*, and present its results. Moreover, various excellent experts are invited to present the issues and methods of water and wastewater management, as best practices for implementing Circular Economy in the water and wastewater management sector, including organisational solutions, technological and educational and informational activites. The conference, organised by the Division of Biogenic Raw Materials in the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in cooperation with the Kraków Water, and it is held in a picturesque place: the historic Bielany Water Treatment Plant. This book of abstracts contains all the oral and poster papers presented at the conference. I hope this is a "knowledge pill" about CE in the water and sewage sector.

Assoc. Prof. Marzena Smol
Chair of CEwater conference

The concept of integrated water management and protection strategy for Dal Lake in Jammu and Kashmir Union Territory, India

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Jammu and Kashmir is a region administered by India as a union territory and is named after the two regions it encompasses – the Jammu region and the Kashmir Valley. The Kashmir valley is one of the top tourist destinations in India, famous for popular ski resort and home to the world's highest green golf course. It is also famous for its scenery, flower gardens and apple farms. It attracts tourists for its unique handicrafts and the famous Kashmir shawls. Dal Lake, a crown of Kashmiri civilization, has strong connection with the socioeconomic value and is critical resource for the local communities and ecosystems. The peoples living around and within the islands of the lake derive their livelihood from the lake in the form of tourism, agriculture, fishing, and vegetable farming. However, during the past few decades due to anthropogenic activities, urbanization and climate change the lake ecosystem and water quality have degraded and the level of water decreased. The main sources of Dal Lake pollution are untreated sewage discharge, agricultural runoff, and waste from the adjoining catchments. The lack of appropriate system approach to the protection of the Dal Lake ecosystem leads to a constant deterioration of the situation. The poster presents the holistic concept of integrated management of lakecatchment system and propositions of ecological restoration strategy for the Dal Lake. Sustainable water management practices are needed to implement within the catchment that involves such aspects as hydrology, land use, socio-economic and legal aspects, and adaptation to climatic changes.

Keywords: Dal Lake, water management, protection strategy, ecosystem degradation

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Water reclamation technologies - challenges and benefits

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Water scarcity presents a pressing global challenge, prompting the exploration of innovative solutions to augment diminishing freshwater resources. Water reclamation technologies offer promises of alleviating water stress while addressing environmental concerns. This paper discusses the challenges and benefits associated with water reclamation technologies. The review of available data on water reclamation technologies was based on the analysis of current, available publications using the desk research method.

Challenges in water reclamation include technological, regulatory, and public perception barriers. Technologically, achieving high-quality reclaimed water requires advanced treatment processes to effectively remove contaminants. Regulatory frameworks governing water reuse often lack uniformity, hindering widespread adoption. Public perception, influenced by concerns over health risks and aesthetic preferences, can hamper acceptance despite scientific assurances. In contrast, the benefits of water reclamation technologies are numerous. Primarily, these technologies offer a sustainable solution to increase water supplies, reducing reliance on increasingly scarce freshwater sources. By treating wastewater to meet specific standards, reclaimed water can be used for various non-potable applications, such as irrigation, industrial processes, and even potable reuse in some cases. Economic benefits also accompany water reclamation technologies, albeit with initial investment costs. Reclaimed water can create new revenue streams through the sale of treated wastewater for industrial or agricultural purposes.

In conclusion, while challenges persist, the benefits of water reclamation technologies are substantial and diverse. Addressing technological, regulatory, and social barriers is crucial to realising the full potential of reclaimed water in sustainable water resource management.

Keywords: water management, water security, wastewater treatment, drivers and barriers, water reuse

Acknowledgments: The paper was carried out under the subsidy of the Division of Biogenic Raw Materials of Mineral and Energy Economy Research Institute, Polish Academy of Sciences and as a part of research of the project "waterCEmanagement in practice - developing comprehensive solutions for water reuse and raising awareness of the key role of water in the transformation process towards a circular economy (CE)" which uses funding worth 323 549,34 euro received from Iceland, Liechtenstein and Norway under the EEA Funds. The aim of the project is to strengthen the transformation towards a circular economy in the field of circular water resources management.

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CEforestry - innovation in forestry biomass residue processing: towards circular forestry with added value products

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Volumes of underutilized forestry biomass residues (bark, needles, cones etc.) in the Baltic Sea region are huge and countries are in different development phases in relation to the utilization of forestry side streams. In many cases these side streams are used as lower value products e.g. bioenergy, however biomass is an ultimate resource for isolation of high value compounds with various applications. The objective of CEforestry is to develop new and innovative practices (circular economy concepts) in forestry and novel solutions to utilize forestry side stream in BSR. This will be achieved through innovative means of collaboration across sectors (researchers, target SMEs, large companies and other relevant actors) and demonstrated in pilot facilities. 4 solutions as pilot activities are planned for use /upscale. A Circular Economy business model will be developed based on the project results and the aim is to propose recommendations to utilize forestry side streams in BSR countries in order to meet EU Green Deal, EU Circular Economy and Baltic Sea region bioeconomy strategy goals. The results from the project will benefit circular forest economy and enterprises interested in refining sustainable novel products. The activities will involve target groups, 12 partners and 18 associated partners from Poland, Latvia, Lithuania, Finland and Sweden.

Keywords: Circular Economy, biomass residue, food, cosmetic, wastewater

Acknowledgments: The Financial support from Interreg Baltic Sea Region is acknowledged.

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Optimization of biochar filter for handwashing wastewater treatment and potential treated water reuse for handwashing

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Portable handwashing stations are key to fighting the transmission of water-borne diseases. However, in settings lacking piped drainage systems, handwashing wastewater (HW) is commonly discarded into the ground. Aside from damaging the environment and public health, this practice wastes low-polluted water resources that can be recycled. This study optimized biochar filtration parameters such as particle size (0.5 – 2 mm), filter depth (15 – 30 cm), and flow rate (1 – 2.5 L/h) to remove color, turbidity, phosphates, and *E. coli*) from HW using Response Surface Methodology. Fifteen configurations were evaluated to study the combined impact of filtration parameters on selected pollutants removal. Quadratic models provided the best fit for pollution removal data. Optimal conditions were 1.25 mm particle size, 30 cm filter depth, and 1 L/h flow rate, corresponding to predicted removals of 97.06, 97.50, 82.67, and 73.06% for color, turbidity, phosphates, and *E. coli*, respectively. Models were validated by evaluating biochar filter performance under optimum operating conditions. Removal efficiencies of 97.63, 99.85, 85.94, and 76.08% for color, turbidity, phosphates, and *E. coli*, respectively, agreed with predicted values. Moreover, the optimized biochar filter removed 56.3, 94.5, 6.1, 92.4, 61.3, 54.7, and 4.3% of COD, TSS, nitrates, ammonia, hardness, sulfates, and chloride, respectively. Treated water quality complied with international drinking and water regulations. Biochar filtration can be a low-cost technology for HW cleaning and recycling along portable handwashing stations. Thus, biochar filtration can sustainably manage water in the circular economy context and help achieve clean water and sanitation (SDG 6).

Keywords: biochar filter, Circular Economy, handwashing, sustainability, water recycling

Acknowledgments: Our sincere gratitude goes out to the Centre for Agroecology, Water and Resilience at Coventry University (UK) for providing us with the graduate scholarship grant (Project Code 13911-06). We want to acknowledge the UK Biochar Research Centre for providing biochar samples for the construction of the filtration units.

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Water recovery and reuse in India

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In India, the predominant water assets are over used resulting in declining water levels and high-water contamination because of blending of surface and ground water with complex pollutants. The sector of water and wastewater, with a specific focus on the reuse of wastewater, has recently attracted attention due to escalating water issues, notably in cities facing scarcity, underscoring the valuable resource aspect of wastewater to alleviate gaps in water supply and demand. The disturbing water accessibility circumstance in India has fueled the need to look for elective water expansion techniques. Reports show that if 80% of metropolitan wastewater could be treated by 2030, there would be a boost of 400% in the volume of accessible wastewater to recover and straightforwardly reuse. Considering the rising population, water reuse in the industrial areas has increased in the previous many years however in the civil area, it is yet to advance. Nutrients and water found in domestic treated wastewater are significant and can be reutilized in metropolitan farming. Greywater treatment and reuse is one of the achievable choices in agricultural nations like India to defeat this issue. The evaluation of the current strategy system for empowering water reuse frameworks shows that the administrative design in regard of wastewater recovery and reuse is in initial stages in India. Continued collaboration among stakeholders and sustained investment are essential to achieving greater resilience in water resource management and ensuring a sustainable future for India.

Keywords: India, wastewater, agriculture, nutrients, contamination

Acknowledgments: The project “waterCEmanagement in” uses funding worth 323 549,34 euro received from Iceland, Liechtenstein and Norway under the EEA Funds. The aim of the project is to strengthen the transformation towards a circular economy in the field of circular water resources management.

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The potential of waste: assessing the impact of liquid anaerobic digestates on plant growth

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Food waste is set as priority goals in the Circular Economy Action Plan adopted by the EU. The use of anaerobic digestion (AD) for treatment of food waste is a candidate for the bio-refinery processes.

In this study, the impact of the digestate from anaerobic digestion of food waste (FWD) with addition of fish sludge (FS) through direct soil tests was examined. Fish sludge is a waste from recirculated aquaculture systems (RAS) consisting of uneaten fish feed and faeces. A preliminary investigation involving a broader concentration range of 2.6-26 ml digestate/kg soil (24-236 ml/m^2 plate) was conducted using Phytotoxkit™ with garden cress (*Lepidum sativum*), focusing on root and stem length as parameters. A more extensive pot experiment, spanning 3 weeks, incorporated also common wheat (*Triticum aestivum*), with analyses centered on the length of the aboveground part and plant dry weight.

The Phytotoxkit™ assay revealed that all concentrations of the digestates inhibited the stem and root growth of *Lepidum sativum.* In the pot experiment, FFWD at a concentration of 1.3 ml digestate/kg soil (55 ml/m^2 pot) stimulated shoot growth but hindered biomass yield. Both digestates, at a concentration of 2.6 ml digestate/kg soil (111 ml/m^2 pot), promoted the growth of garden cress in terms of biomass and shoot height. However, no significant stimulation of aboveground part growth was observed for any of the *Triticum aestivum* plants.

Future research should encompass the pre-incubation of amendments in the soil before plant sowing, along with an assessment of the effects on other plant species.

Keywords: anaerobic digestates, soil amendment, Phytotoxkit™, pot experiment

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Extracellular DNA adsorption on electric arc furnace dusts

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The presence of extracellular DNA (exDNA) in wastewater is one of the factors of virulence genes and antibiotic resistance genes (ARG) propagation in the aqueous environment. Due to the low effectiveness of exDNA removal by traditional wastewater treatment, alternative methods must be utilized (Lu et al., 2021). Our research aims to develop the adsorbent for efficient exDNA removal. Motivated by the idea of the Circular Economy - repurposing waste materials - a magnetic fraction of electric arc furnace dust (EAFD), composed mostly of iron oxides, were utilized as a raw material for adsorbent production. This study presents the process of functionalization of EAFD and explores its application as adsorbent for exDNA. The functionalization process involved partial dissolution of EAFD in a 1 M HCl solution, followed by the precipitation of iron oxo-hydroxides using an alkaline solution (sodium or calcium hydroxide). In the result of functionalization process a sevenfold increase in specific surface area is observed. Recorded FTIR spectra of the functionalized materials revealed intensity increasement in bands attributed to stretching and bending vibrations of O-H groups in the range of 3600-3100 and 1680-1600 cm^{-1} respectively, both associated with the precipitation of iron oxo-hydroxides. Conducted adsorption experiments showed that functionalized, calcium hydroxide treated EAFD performed best in every examined condition, exhibiting up to a twofold increase of adsorption capacity [0.75 mgDNA/g] compared to the initial EAFD. The proven, high adsorption capacity toward exDNA indicates the possibility of application in wastewater treatment. Furthermore, materials can be conveniently recovered from the solution through a magnetic separation due to their ferrimagnetic properties.

Keywords: exDNA, EAFD, magnetic separation, iron oxo-hydroxides

Acknowledgments: This research was financed by the National Science Centre, Poland Grant No. 2021/41/B/NZ9/01552.

Phosphorous recovery in the form of struvite from post-processing liquid from the hydrothermal carbonization of sewage sludge treated by the membrane technique

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Proper management of sewage sludge requires innovative techniques for its disposal. One of the most promising alternatives is hydrothermal carbonization, which results in solid (hydrochar) and liquid (post-processing) products. This process not only greatly reduces the volume of sewage sludge, but it also enhances its dewaterability and improves water removal. Unfortunately, the post-processing liquid poses significant problems due to the presence of toxic compounds. Therefore, to ensure the sustainable management of the process, the proper treatment of post-processing liquid has to be introduced. This study presents the membrane filtration of post-processing liquid as its treatment process. Moreover, due to the fact that post-processing liquid contains a high amount of phosphorous, a combination of membrane filtration with a struvite precipitation process has been proposed. Membrane filtration was performed through different membrane such as polymers, cellulose and ceramic membranes, resulting in permeates, which were investigated for their physical and chemical properties. Then, struvite precipitation was performed on post-processing liquid and SEM analysis was conducted on the struvite and selected membrane surfaces to study their morphological structure. Furthermore, the impact of struvite precipitation on membrane properties was investigated. Consequently, key parameters were determined including membrane relative permeability, degree of recovery, and permeate flux for each process. Notably, the type of membrane used significantly influenced the properties of the permeate. Membranes composed of polyethersulfone exhibited distinct behaviour compared to those made of regenerated cellulose. Concluding, the purification process of post-processing liquid derived from the hydrothermal carbonization of sewage sludge might improve its sustainable disposal.

Keywords: hydrothermal carbonization, post-processing liquid, struvite precipitation, membrane filtration

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Green hydrogen toward sustainability

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The issue of sustainability involves different categories of stakeholders and concerns multiple sectors. However, challenges should always be viewed from a pragmatic and not an ideological perspective. Therefore, the principle of compromise turns out to be fundamental. Indeed, on the one hand, green hydrogen obtained from renewable sources supports decarbonization goals; on the other hand, its development also requires significant water use. In fact, electrolysis requires about 9 liters of water to produce one kilogram of green hydrogen. This analysis focuses on the economic sphere and thus aims to calculate the Levelized Cost of Hydrogen (LCOH) through the discounted cash flow method considering a useful life of 25 years. The size of the electrolysis plant is set equal to 267 kW and the energy is produced by a photovoltaic plant. The results show an LCOH in the base case scenario of 3.65 €/kg. However, variables may fluctuate and in order to give robustness to the results, alternative analyses are conducted. Focusing on the capex of the electrolysis plant the LCOH varies between 3.37-3.92 €/kg, while varying the capex of the photovoltaic plant shows a variation between 3.26-4 €/kg. Thus, the cost may fluctuate and it should be considered that its value may increase as a result of the various components along its production chain, identifying a much more significant selling price. The challenge of the Circular Economy joins that of the green economy, and the development of green hydrogen is linked to the efficient and rational use of water resources.

Keywords: economic analysis, green hydrogen, Sustainability

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Rainwater and gray water recovery systems - criteria for comparative evaluation of environmental, economic and social aspects

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Water recovery is a key component of the European Union's environmental policy, as it helps reduce pressure on water resources while ensuring access to clean drinking water, supporting agriculture, industry and other economic sectors. Funding programs support investments in rainwater and gray water treatment systems, which enable the reuse of reclaimed water in industrial processes, agricultural irrigation and urban retention systems. Evaluating the effectiveness of these systems is a complex process that requires consideration of many aspects and a holistic approach to the problem.

The paper aims to verify the criteria for the comparative environmental, economic and social evaluation of water recovery systems, with a focus on rainwater and gray water. Criteria for evaluating the environmental efficiency of water recovery systems were created based on direct environmental aspects, mainly related to environmental assessment, such as air, water and soil quality, natural resource and energy consumption, as well as local problems (noise, vibration, odor, visual effect, etc.). The indicators used for economic analysis methodology and cost-benefit analysis (CBA) were used to determine the criteria for evaluating economic efficiency. This paper also presents criteria for evaluating social aspects, which have been identified according to the social dimension of the Sustainable Development Goals in the framework of monitoring the Circular Economy in the water and wastewater sector. The analysis of these criteria allows a detailed evaluation and selection of water recovery systems, which can bring many benefits, such as reduced drinking water consumption, reduced sewerage load and reduced risk of water shortage, but also financial savings. The implementation of environmental, economic and social evaluation criteria could help support more sustainable water management decisions.

Keywords: water reuse, rainwater, grey water, environmental criteria, economic criteria, social criteria

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Biochar from algae Chlorella sp. as a plant stimulator

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The aim of the work was to use biochar produced from the biomass of algae *Chlorella sp.* as a means of stimulating plant germination. Algae *Chlorella sp*. cultures were prepared on the basis of the synthetic BG-11 medium. The biomass was separated from the substrate by sedimentation and centrifugation, and then dehydrated in the freeze-drying process. Dry biomass was pyrolysed at a temperature of 400°C in an atmosphere of carbon dioxide. The biochar obtained as a result of the pyrolysis of algae biomass was characterized by a porous structure and the presence of functional groups in bands located in the range of 2000 – 1500 cm^{-1} and 1500 – 650 cm^{-1}. In the obtained material, the presence of a D band in the range of 1346-1354 cm^{-1}, which corresponds to disordered carbon structures, and G band in the range of 1585-1594 cm^{-1}, originating from stretching vibrations, was found. The obtained biochar was tested as a stimulator of radish seed germination. Two radish cultures were prepared in which cotton wool with the addition of 0.2 g of the obtained biochar and a reference sample without biochar were used as the substrate. 50 seeds were placed on each plate. The cultures were systematically watered with distilled water. The culture time was 14 days. Seed germination measurements consisted of determining the average germination time (1.55 for the culture fed with biochar and 2.24 for the reference culture), germination energy (94% for the culture with biochar, 88% for the reference sample), germination capacity (96% for the culture with biochar and 89% for the reference sample). The measurements also included measuring the length of the sprouts and weighing them. The length of sprouts in cultures with biochar was 3.5 cm, the weight was 3.2 g, and the reference samples were 2.1 cm and 1.9 g, respectively. Obtained as a result of the pyrolysis process of microalgae biomass, biochar is characterized by parameters such as porous structure, chemical composition, presence functional groups, which makes it possible to use it in agriculture. The study confirmed the possibility of using biochar from the biomass of *Chlorella sp*. microalgae as a means of stimulating the growth of radish seeds. The presented topics may be a response to current environmental protection problems related to mitigating the effects of climate change.

Keywords: biomass, algae, biochar, plants, stimulator

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Issues of rainwater and swimming pool water reuse, case study

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This work investigates the issues and technological aspects of water reuse and harvesting for promoting integrated urban water in the small city. The case study is the city c.a 16 000PE in Poland, equipped with a separate sewer and drain network. The city has already faced droughts and floods and the high maintenance cost of the Municipal Sports Center with swimming pools and football fields. Thanks to the project WaterMan it is possible to elaborate, propose, and construct an integrated system for the reuse of swimming pool water mixed with roof-harvested precipitation as well as redesign parking lots for the retention of surface runoff in green infrastructure like rain gardens, bioswales and infiltrations zones. The analyses of mixtures of swimming pool water and water withdrawal from the system revealed a list of emerging pollutants that should be removed before reusing for safety reasons according to EU Regulation 2020/741. Thus two technological lines with unit treatment processes have been proposed and tested. Optimization of the selection process of best technology in this case will be described.

Keywords: integrated urban water cycle, water reuse, swimming pool water, treatment

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Is the Italian water sector sustainable? An empirical analysis by DEA

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One of the most important challenges facing water resource development is sustainability. Significant increases in water demand and pollution are caused by natural processes, economic pressures, and population growth; these trends are not bolstered by extremely inefficient water supply methods. This framework explains the rationale behind the drastic restructuring implemented by Law 36/1994 (Act n. 36 on Water Resources, 1994). The Italian water services, with their fragmented management, highly deficient collection and treatment of wastewater, and existing and potential problems in water supply in some areas of the country, are to blame. The imposition of a "for the market" competition to take advantage of potential economies of scale and scope was decided by the impossibility of avoiding natural monopolies and the need to industrialize the entire industry. In this work, the sustainable efficiency of the Italian water sector is evaluated using a set of key variables, such as water losses (never considered in the previous studies), using mathematical/linear programming of Data Envelopment Analysis (DEA) on a group of Italian water utility companies. This well-known method helps policymakers by providing corrective policies and procedures that could make the inefficient units efficient, in addition to measuring the efficiency of each unit in the system. Policy makers may find this method helpful in focusing their decisions on creating a more sustainable and effective water sector.

Keywords: water industry, efficiency, Sustainability

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Adaptation to water shortage and its barriers in water-scarce rural settings in eastern Ethiopia: a qualitative study

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Water shortage is a crucial public health and developmental challenge for many communities worldwide, particularly in low- and middle-income countries. In Ethiopia, most rural households are excluded from pipeline distribution, and households utilize alternative water sources. In those regions, water is scarce, and its availability is unpredictable. The unpredictability creates a need to use different adaptation strategies. This study uses qualitative methods to examine how communities adapt to water shortage and the adaptation barriers in eastern Ethiopia. We employed Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) using semi-structured guides to explore the community's water use experiences. The FGDs were performed among female and male community members, and the KIIs involved health extension supervisors, health extension workers (community health agents), Regional Water, sanitation, and Hygiene (WASH) coordinator, and rural water and sewerage expert. A thematic analysis was performed as a principal analytical approach using NVivo software. Two main themes, four sub-themes, and twelve sub-categories emerged from the thematic analysis. Water shortage affected almost all participants from all socio-economic backgrounds, and households used several adaptation techniques to reduce the risk and impact. The findings indicated construction of water sources, storing water using different-sized containers, water purchasing, looking for an alternative water source, water treatment at point-of-use, and water sharing were the common adaptation strategies. The study also pinpointed six adaptation barriers. The study indicated unreliable water supplies impose significant adaptation burdens on households, particularly economically poor households, which share the bigger challenge.

Keywords: water shortages, adaptation, adaptation barriers, rural water supply, qualitative study

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Enhancing water reuse: fusion of electroprocesses and thin-film plasma-based catalytic ozonation

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In response to the urgent need for sustainable environmental solutions, this paper explores innovative approaches to facilitate efficient water-reuse cycles. Central to achieving this goal is the optimization of wastewater treatment technologies, often relying on complex multi-stage systems incorporating advanced oxidation processes (AOPs). Given the pressing concerns surrounding contaminants of emerging concern (CECs) in effluents, implementing advanced oxidation processes for their efficient removal is paramount. Recent advancements in thin-film nanocatalysts, deposited via cold plasma onto structured supports, show promising potential for enhancing process efficiency, particularly in wastewater ozonation. The research focuses on evaluating the enhanced effectiveness of eliminating a mixture of CECs including the neuro-active insecticide imidacloprid (IMI), sulfonamide antibiotic sulfamethoxazole (SMX), and endocrine disruptor butylparaben (BuP). This evaluation compares single electrochemical processes and single ozonation with a combined hybrid technology incorporating thin-film plasma-based catalysts. This hybrid technology overcomes the limitations of each individual treatment method, resulting in high-quality purification outcomes. The innovative approach addresses the challenges posed by CECs in wastewater, offering a promising solution for sustainable water management and meeting environmental goals. Alternative technologies, such as newly developed plasma-deposited thin films in hybrid catalytic ozonation combined with electrochemical processes, present a cutting-edge approach to water reuse, aiming for cost-effective and sustainable wastewater treatment solutions. This highlights the pivotal role of innovative technologies in addressing environmental challenges and advancing the goals of the Green Deal in water and wastewater management.

Keywords: thin-film catalysts, cold plasma, micropollutants, ozonation, water reuse

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Enhancing ammonia oxidation (AOR) through electrochemical olarization: NiCu-S/NF electrocatalyst

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To produce high-purity hydrogen with less energy consumption ammonia oxidation reaction (AOR) has the ability to replace the oxygen evolution reaction (OER) in water splitting. AOR emerged as a potential technique due to its lower overpotential over OER, and preventing the mixing of hydrogen and oxygen. Transition metals-based anodes are one of the most effective and environmentally friendly for the AOR process.

Thus, we synthesized a highly efficient $Ni_{0.5}Cu_{1.5}$-S deposited on Nickel foam and later reconstructed in an alkaline solution by two different methods cyclovoltammetry (CV) and chronoamperometry (CA) and studied its AOR performance. The formed $Ni_{0.5}Cu_{1.5}$-S/NF_CV Mott-Schottky heterojunction exhibits high current density 152.54 mA/cm^{-2} at 1.55 V vs RHE Moreover, the electrode has a large TOF (s^{-1}) 0.1424 and excellent stability for 24 hours.

Energy dispersion spectroscopy (EDS) shows that electrochemical polarization increases the oxygen content up to 35% and reduces the sulfur content up to 80%, indicating the transformation of metal sulfide to metal (hydroxyl) oxide. X-ray diffraction measurements demonstrated the existence of surface reconfiguration, which promotes the formation of true active species (NiOOH, NiO_2, and Cu_2O). After 5 hours of electrochemical testing the concentration of ammonia decreased up to 70 percent confirming the oxidation of ammonia. According to the experimental findings, we proposed a possible pathway for ammonia oxidation reaction based on the electrochemical polarization of the $Ni_{0.5}Cu_{1.5}$-S/NF. This study enriched the in-depth understanding of ammonia oxidation and provided a very promising way to produce hydrogen.

Keywords: ammonia electrooxidation reaction (AOR), Mott-Schottky, electrochemical polarization, surface modification, heterojunction

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Mitigation of hydrogen sulphide in municipal wastewater facilities - spruce bark extract as biocide replacement

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In treatment of wastewater, and in the cellulose industries, large amounts of synthetic biocides are consumed to control growth of unwanted microbes. The microbes cause problems by formation of biofilm, corrosion of pipes, and gas production. In stored pulp formation of hydrogen gas (H_2), and in waste water facilities formation of toxic and bad smelling hydrogen sulphide (H_2S), are common issues. This is often handled by addition of various synthetic chemicals. The objective is to evaluate the effect of spruce bark extract as biocide replacement, especially to mitigate H_2 and H_2S formation in wastewater and industrial processes.

We have developed environmentally good alternatives to synthetic biocides, based on regional low-value materials from the forest industry. Hot water extraction of milled spruce bark was performed at LUKE, Finland.

Bacteria were collected from the municipal waste water system and from pulp and process water at a papermill. Many different microbial species were isolated and represented Gram-positive, Gram-negative, aerobic, and anaerobic bacteria, spore-formers and non-spore formers. Also, filament forming bacteria were found (*Beggiatoa* sp. and *Thiotrix* sp). Some of the investigated species are known to produce H_2S.

Minimal inhibitory concentrations (MICs) of the spruce bark extract was determined by agar dilution technique. It was demonstrated that a majority of the studied bacteria had MICs ≤0.5 % (w/v).

Conclusion: It seems possible to use the spruce bark extract to decrease the number of challenging microbes. Studies in larger scale are needed to confirm this hypothesis.

Keywords: biocide replacement, spruce bark extract

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Resource wastewater – energy and nutrient recovery success stories

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In 2015, the global community, represented by 193 nations, has set itself ambitious goals - 17 Sustainable Development Goals, six of which are directly or indirectly related to water. To achieve these goals, economic growth must at least be decoupled from material use - we must produce more wealth or wellbeing with less material. Our study of European success stories shows the eminent contribution that wastewater and sewage treatment plants can make. By operating heat pumps and using sewage sludge for biogas production, plants can generate up to ten times the energy they consume in the form of district heating, district cooling and liquid or gaseous renewable fuels. Efficient energy conversion can be well integrated with very efficient wastewater treatment, which removes 100% of solids, 99% of BOD and phosphorus, and 86% of nitrogen. Solids and nutrient removal is a prerequisite for material recovery from wastewater: after anaerobic digestion, sanitation and solid/liquid separation, the two fractions could be returned to land, albeit with the trade-off of recycling heavy metals and emerging contaminants such as PFAS and plastic particles, among others. Alternatively, nitrogen and phosphorus can be extracted sequentially and returned to soils as high grade, use efficient and high purity fertilisers, particularly if extracted from ash after additional energy conversion in sludge-to-energy plants. Several technology companies offer mature processes that in some cases recycle not only nutrients, but also iron and aluminium as coagulants for reuse in the wastewater treatment plant, and silica sand with pozzolanic properties similar to Portland cement. The most sophisticated solutions have complex flow sheets but comparatively small environmental footprints, as each material is returned to the use for which it was originally designed and engineered.

Keywords: resource wastewater, heat pump, phosphorus, nitrogen, coagulant

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Struvite recovery from sewage sludge liquid using $Mg(OH)_2$ and $MgCl_2$

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The aim of the research was the quantitative and qualitative determination of struvite formation in laboratory conditions from the supernatant of the sewage sludge dewatering process coming from a municipal wastewater treatment plant. The research was carried out as part of the Norway Grants project SIREN, the topic of which is the recovery of valuable resources in municipal wastewater treatment processes. The test stand consisted of four reactors with an active capacity of 1.5 liters, equipped with mechanical frame stirrers, 120 rpm. Struvite was obtained in two ways: by adding Mg in the form of magnesium hydroxide or magnesium chloride to a phosphate-rich sludge liquid. The physico-chemical-crystalline characteristics of the formed struvite were investigated. Its purity was determined using advanced analytical methods: Raman spectroscopy and powder X-ray diffractometry. In the case of $Mg(OH)_2$, optimal conditions for struvite precipitation were recorded after 30 minutes of mixing combined with 24 hours of stand out at Mg/P-PO_4 molar ratio of 1.2:1 at pH 8.5. The most satisfactory crystallization effects for $MgCl_2$ were recorded at higher molar ratio of 2.2:1 at pH 9.0. A clear difference in the shape of the crystals were observed depending on the magnesium source used (prismatic habit for magnesium hydroxide, cross habit for magnesium chloride). Laboratory tests confirmed the possibility of effective recovery of phosphorus in the form of low-contaminated struvite from sludge liquors.

Keywords: struvite, phosphorus recovery, sludge supernatant, wastewater

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LCA of energy production at wastewater treatment plants

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The new Wastewater Directive requires treatment plants to aim for energy self-sufficiency. The move towards energy self-sufficiency intends to mitigate climate change by reducing greenhouse gas emissions. For large facilities, the natural solution is to obtain energy through methane fermentation, newer substrates being sought to increase the amount of biogas produced. However, the increase in biogas production should not be the only assessment criterion. Indeed, the use of some cosubstrates may increase the overall environmental burden. For smaller wastewater treatment plants, it will be natural to use locally available raw materials, but also solar, wind, and water energy. From the point of view of reducing greenhouse gas emissions, understood as both direct and indirect emissions, methods for increasing energy self-sufficiency should also be assessed in terms of total environmental burdens, using the life cycle assessment (LCA) methodology.

This study aims to carry out an LCA of energy production in wastewater treatment plants, including methane digestion and co-digestion. For this purpose, a methodology for the LCA assessment of the energy production at wastewater treatment plants was developed, with the definition of the purpose of the analysis, the functional unit and system boundaries, the analysis of the set of inputs and outputs - including the selection of processes, the selection of Life Cycle Impact Assessment methodologies, the performance of calculations in SimaPro and the interpretation of the results. The result of the work is the selection of energy production methods that not only increase the energy self-sufficiency of the wastewater treatment plant, but also contribute to the reduction of greenhouse gas emissions.

Keywords: wastewater treatment plant, energy, digestion, LCA, carbon footprint

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Exploring lactic acid and organic acid production in rice and potato fermentation: a comparative analysis with ph-dependent effects

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This study explores the dynamics of lactic acid fermentation using rice and potato substrates under varying pH conditions, with the goal of enhancing lactic acid production by optimizing the process. Lactic acid, an essential element in many biological and industrial processes, demonstrates diverse production patterns based on fermentation conditions, such as the type of substrate and the pH of the environment. To compare the efficiency and kinetics of lactic acid production using rice and potato substrates, we conducted fermentation experiments under three different pH conditions: uncontrolled, pH 6, and pH 8. The results of our study revealed substantial variations in lactic acid production between the substrates tested. Rice consistently yielded slightly higher concentrations of lactic acid over a more extended period compared to potato. At a pH of 6, rice produced a lactic acid concentration of 53.88g/L after 72 hours, while potato reached 52.3 g/L within 48 hours. The study also found that rice fermentation produced a wide range of volatile fatty acids (VFAs), suggesting a diverse microbial activity, which was less prominent in potato fermentations. This research aims to determine the optimal substrate and pH conditions to produce lactic acid. Obtaining knowledge about the connection between the type of substrate, pH levels, and microbial activity can greatly improve the effectiveness of lactic acid fermentation processes, providing a means to develop more environmentally friendly and economically efficient production methods. This innovation is essential for supporting the shift towards a circular and sustainable economy, where all stages of production are optimized to minimize waste and enhance value extraction.

Keywords: fermentation, lactic acid, volatile fatty acids, rice-based fermentation, potato-based fermentation

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The use of UVC radiation supported by biopreparations for disinfection of treated sewage

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Discharging treated sewage into rivers may pose a potential risk to both the aquatic ecosystem and human health. This threat results from the presence of various pathogenic microorganisms in sewage. Although treatment processes typically reduce the number of bacteria by approximately 99%, the remaining amount of fecal bacteria entering the recipient is significant and dangerous, which is why the use of the third stage of wastewater treatment is so important.

Various methods of wastewater disinfection have been used for years. The main advantage of ultraviolet radiation is that no additional chemicals are released into the environment and no disinfection by-products are produced. However, physical processes also have their drawbacks: their effectiveness largely depends on the body's sensitivity to radiation, and the use of this method has a local effect and does not protect against re-contamination.

The use of effective microorganisms can be a method supporting UV disinfection processes. Currently, biopreparations are widely used to support the biodegradation processes of organic substances and the transformation of inorganic compounds.

The paper presents the results of research on the effectiveness of UV radiation supported by biopreparations in wastewater disinfection processes, based on indicator bacteria: *E. coli* and Coliform bacteria. The research took into account the influence of light and temperature on the recovery of microorganisms after disinfection with UV radiation. The influence of the substrate on which microorganisms multiply and the form of application of the biopreparation were taken into account. Traditional and modern methods were used to assess the microbiological quality of wastewater.

Keywords: municipal sewage, disinfection, UV radiation, biopreparations

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Methane production intensification by mid-temperature alkaline pre-treatment of waste activated sludge: results of semi-continuous anaerobic digestion

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Currently, the role of wastewater treatment plants (WWTP), in addition to ensuring the appropriate quality of wastewater discharged into the environment, is to strive for climate neutrality. The first step to achieving this goal is to ensure energy self-sufficiency, or even excess energy production. This can be achieved by increasing methane production in the anaerobic digestion process (AD). The main aim of the presented research was to determine the effect of mid-temperature alkaline pretreatment of waste activated sludge (WAS) on methane production increase. Alkaline reagent dose, process temperature and time for WAS disintegration were 16.0 g NaOH/kg TS, 60^{o}C and 30 minutes, respectively. Semi-continuous mesophilic (37^{o}C) AD trials were carried out in two parallel 15-liter reactors with on-line biogas production monitoring and periodic control of biogas composition, one was fed with WAS (reactor M1) and second with pretreated WAS (reactor M2) with total solids concentration about 5%. The results showed that at 21 days sludge retention time (SRT) methane production was 200±8 NmL_{CH4}/gVS_{in}, and 230±27 NmL_{CH4}/gVS_{in} in reactor M1 and M2 respectively. Pre-treatment resulted in 15% methane yield increase. Higher methane production corresponded to better volatile solids (VS) reduction equal 34.8±3.1% and 39.6±5.5% in M1 and M2, respectively. Shortening the SRT to 18 days resulted in a significant reduction in methane yield, to 86±13 NmL_{CH4}/gVS_{in} and 129±12 NmL_{CH4}/gVS_{in} and VS reduction lowering to 28.0±5.8% and 37.2±3.9%, in M1 and M2, respectively. The 16s rRNA sequencing analysis was conducted to reveal microbial community changes during trials.

Keywords: mid-temperature pretreatment, alkaline pre-treatment, waste activated sludge disintegration, methane potential, semi-continuous trials

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Adapting the small-scale wastewater treatment to tourism-driven seasonality in the Baltic Sea Region – experiences from the Nursecoast - II INTERREG Project

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Wastewater flows discharged from the Baltic coast regions vary significantly due to tourism seasonality. In some BSR regions the amount of tourists can exceed the local population even 20 times. However, wastewater treatment plants (WWTP) designed according to the needs of local population, are often too small, e.g. under 2000 PE, which leads to serious problems. The Nursecoast project aims at finding solutions, that would reduce the nutrients discharge to Baltic sea, even in the summer touristic season. The adaptation to high seasonality requires approach broader than just technological solutions, i.e. a comprehensive method to address all relevant issues.

Novel strategies, studied in 6 pilots built in Denmark, Poland, Latvia and Finland, include: (1) wastewater micro and nano-aeration, (2) reuse of wastewater from constructed wetlands in agriculture, (3) nature-based solutions to treat excess wastewater in the summer and (4) greywater and sludge management. The first project results include a comprehensive inventory of WWTP in the BSR coastal regions, presented in the GIS format, pilot technical descriptions, thorough N and P use technology review and surveys of state-of-the-art wastewater seasonality. These data cover location, basic effluent parameters like flowrate, BOD, COD, etc.

The collected information can help local authorities (the project target group) to manage the wastewater flows in a better way. The project's outcomes are expected to provide valuable insights into sustainable wastewater management practices in tourist regions, thus contributing to environmental conservation in the Baltic Sea.

Keywords: nutrients reduction, small wastewater treatment plants, constructed wetlands, micro-aeration, wastewater reuse

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Content of heavy metals in washed mineral waste from grit chambers, fly ash from a thermal treatment of municipal sewage sludge, mixtures of both types of wastes and their eluates, along with an assessment of the possibilities of using these wastes as soil backfill and road embankment materials

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In Polish wastewater treatment plants, the main method of dealing with washed mineral waste from grit chambers and fly ash constituting waste from a thermal treatment of municipal sewage sludge is their disposal. The indicated wastes management is a high cost for wastewater treatment plants, therefore solutions are being sought that aim to use these wastes in the construction industry, especially as by-products. Such efforts are consistent with the concept of a Circular Economy and would also contribute to achieving selected sustainable development goals, including saving natural sand resources. The research presents the results of laboratory tests of the content of selected heavy metals (zinc, lead, copper, cadmium, chromium, nickel and cobalt) in wastes generated in a wastewater treatment plant in Warsaw, as well as in mixtures of both types of wastes in various proportions. Eluates from these wastes and their mixtures were also conducted. Moreover, mercury, arsenic and tin were determined for characteristic samples of wastes. In one batch of samples of washed mineral waste, the concentration limits of zinc (632.28 mg/kg d.m.) and copper (356.70 mg/kg d.m.) were exceeded. However, in another sample, it was noted that the concentrations of all ten heavy metals were below the limit value. In all eluates, the concentration of heavy metals did not exceed the limit values. The results of eluates indicate the possibility of the safe usage of washed mineral waste from grit chambers, fly ash from a thermal treatment of municipal sewage sludge and their mixtures as materials in indicated applications in earthworks.

Keywords: washed mineral waste, fly ash, wastewater treatment plant, Circular Economy, natural resources

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The effect of process conditions of thermochemical conversion of leather and textile mixtures on the composition and structure of the produced char materials

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The work presents the results of research on the development of thermochemical technology for the conversion of solid waste in the form of the upper layer of post-consumer footwear. Representative samples of this type of waste were ground. As a result of this process, a heterogeneous mixture of leather and textiles was obtained, which was characterized in terms of moisture, dry matter and ash content, heat of combustion and elemental composition. As a result of the tests, it was found that the ground waste samples were dry and free of visible contaminants. They were characterized by low ash content and high heat of combustion, which translates into a high calorific value of the material, which mainly consists of carbon, oxygen and calcium. Moreover, the tested material contains relatively small amounts of sulfur and chlorine, which may be beneficial for its use as a raw material in the thermochemical conversion process and the use of the produced chars as sorption materials.

In the second stage of the research work, ground waste was subjected to pyrolysis processes, which were carried out at temperatures of 500, 700 and 900°C. Based on the results of the tests, it was found that with the increase in the temperature of the pyrolysis process, an increase in mass loss was observed. As a result of the pyrolysis processes, chars were obtained which were characterized by the presence of two bands characteristic of carbon materials: the G band with a wave number of approx. 1590 cm^{-1} and the D band with a wave number of approx. 1350 cm^{-1}. Based on the obtained peak intensity values, ID/IG ratios were calculated, allowing to assess the degree of order in the structure of the tested materials. The char obtained at 500°C (ID/IG=0.03) has the most ordered structure. As the pyrolysis temperature increases, the value of the ID/IG ratio increases (for 700°C the ID/IG ratio is 0.30, and for 900°C - 0.31), and thus the degree of structure disorder increases. In the next stage of work, it was planned to examine the sorption properties of the produced char materials.

Keywords: thermochemical conversion, post-consumer footwear, mixture of leather and textiles, structure of char materials

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Monitoring of the circular economy implementation in Lithuanian water and sewage sector

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Wastewater treatment plants (WWTPs) in Lithuania, similarly to majority of other countries and plants, were originally built and operated according to the concept of linear economy. That is, the main aim was to treat water and sewage sludge. Nowadays, considering the shifting of paradigms towards circularity, it becomes increasingly relevant to implement circular solutions in WWTPs. To understand the status-quo and present the insights into the potential of circularity of Lithuanian WWTPs, an analysis was made using indicators on prevention, removal, reuse, recycling, and recovery.

In terms of prevention, water productivity is rising, water consumption and the resulting amount of sewage are lower compared to other EU countries. Yet, household usage is showing signs of increase, particularly due to irrigation, necessitating intervention and promotion of preventive measures.

EU directives and funding have improved Lithuania's wastewater sector notably, yet connecting smaller areas to centralized networks remains incomplete. Nutrient removal from wastewater is vital to prevent Baltic Sea eutrophication. Progress was made, but setbacks occurred due to population and industry concentration, underscoring the importance of forecasting and timely planning.

Wastewater reuse/recycling is not practiced. Though exploring reuse for non-potable purposes like car washing is feasible even with abundant water resources. Long-term considerations for agricultural reuse may arise with climate change-induced irrigation needs.

Sludge use primarily occurs in agriculture and composting. Sludge incineration is rising, with energy recovery, but technology inefficiencies balance energy gains. Solutions are needed to maximize energy and material potential.

WWTPs hold potential for gas, electricity, and heat production. However, biorefinery applications are yet to be identified.

Keywords: Circular Economy, indicators, wastewater

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The human health risk of polycyclic aromatic hydrocarbons in soils and urban dust from selected green areas of the city of Cracow

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In this study, the levels of 16 USEPA PAHs were investigated in soils and urban dust samples collected from greenfield sites in the city of Krakow.

The concentrations of total 16 PAHs ranged from 407.4 to 19080.6 µg/kg and from 2140.1 to 4900.5 µg/kg for soils and urban dust, respectively. The calculated TEF for the sum of 16 PAHs in soil ranged from 19.2 to 2441.1 µg/kg and from 220.7 to 581.2 µg/kg for street dust samples. The values for Σ7carcPAHs/ΣPAHs ranged from 0.92 to 0.95 for dust and soil, and 0.94 for water samples. The mutagenicity index values ranged from 22.8 to 2719.8 mgBaP/kg for soil and 248.6-657.5 mgBaP/kg for urban dust.

The cancer risk values from adult and child exposure to PAHs through dermal contact and oral ingestion only reached 1.09 $*10^{-5}$ in soils from Plant, suggesting a significant cancer risk associated with human exposure to PAHs in these urban soils.

To reduce the risk of PAHs in the urban environment, the focus should be on decreasing the load of heavy PAHs, particularly BaP, DB, and BbF, on road surfaces, pavements, and park alleys. This can be achieved through frequent flushing and street sweeping.

Keywords: polycyclic aromatic hydrocarbons, urban dust, soil, cancerogenic, mutagenic

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Determination of forever chemicals (PFAS) in drinking water by HPLC-ESI-MS/MS

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PFAS (perfluoroalkylated substances) are a group of aliphatic compounds called forever chemicals due to their common occurrence in many everyday products and their persistence and ability to accumulate in the natural environment including drinking and surface waters. The Drinking Water Directive (2020/2184/EU) sets two group thresholds for PFAS: 'sum of PFAS' (0.1 µg/L) and 'total PFAS' (0.5 µg/L). Poland, as one of the few EU countries, has not yet introduced EU PFAS thresholds for drinking water into national law.

The research on the determination of PFAS in 30 samples of tap water, well water, spring water, and mineral water was performed. Samples were collected in the fourth quarter of 2023 and prepared by solid phase extraction (SPE) using columns with hydrophilic-lipophilic-balanced (HLB) beads. Determination of 'PFAS total' was performed using the high-performance liquid chromatography/tandem mass spectrometry technique with electrospray ionization mode (HPLC-ESI-MS/MS, Shimadzu). Chromatographic separation was performed in a gradient system in ARION® Plus HPLC column (3 µm) connected to the delay column Dr. Maisch ReproSil-Pur Basic-C18, (3µm). A mixture of acetonitrile and water with ammonium acetate additives was the mobile phase. The analyzes were carried out using the most common method of quantifying analytes: multiple reaction monitoring (MRM). 'PFAS total' was determined in all tested samples at a level above the LOQ which is 0.1 ng/L in the developed method. The study carried out showed that tap and well water samples had the highest 'PFAS total' concentration.

Keywords: PFAS, forever chemicals, UPLC-ESI-MS/MS

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Water recovery and reuse in Cracow Water

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Companies operating on water and wastewater systems have a great implementation opportunities in Circular Economy. Water and wastewater treatment, sludge and other waste handling and energy management give a natural potential of water, materials and energy reuse and recovery. The Cracow Water Company runs projects in each of these areas. The development of water recovery is one of the important tasks taken into account in every project related to the modernization of sewage treatment plants. Water recovery systems from sewage in the Płaszów sewage treatment plant allow for its secondary use in technological processes and outside the sewage treatment plant for flushing sewage systems and washing streets in the city. The article presents technological solutions used for water recovery in Płaszów WWTP. The achieved effects were discussed and further development opportunities within the Circular Economy were indicated. Indicators for monitoring the implementation of solutions enabling comparison of water recovery efficiency were also proposed.

Keywords: water reuse, wastewater polishing

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European perspectives and law for water recovery and reuse

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One-third of the European Union (EU) is currently experiencing water shortages, a problem that is expected to worsen due to climate change. This has significant implications for the people, economy, and market stability of the EU. In response to this issue, the EU is promoting the reclamation of processed urban wastewater for non-drinking purposes, such as irrigation, to effectively manage water resources in a sustainable manner. At present, the EU recycles 1 billion cubic meters of wastewater annually, a volume that has the potential to increase by up to six times. To capitalize on this potential, the EU has launched a legislative initiative to encourage and standardize water reuse practices across all its member states.

The Regulation (EU) 2020/741 on minimum requirements for water reuse in agricultural irrigation establishes consistent water quality standards and risk management provisions to ensure the safe reuse of treated urban wastewater, with a focus on safeguarding public health and the environment. The regulation mandates the preparation of Risk Management Plan (RMP) on water reuse systems to promote the secure application of treated wastewater for agricultural irrigation. The Joint Research Centre (JRC) of the European Commission has worked in close collaboration with experts, representatives of EU Member States, and stakeholders to provide guidelines on risk management plan. This presentation will provide a comprehensive look at the technical aspects of components within a risk management plan, as well as practical examples on their application.

Keywords: water reuse, water quality, risk management

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Ecological education of children for water in a circular economy (CE)

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Water constitutes one of the most valuable resources on Earth. In the present times, with the water demand continually escalating, it is imperative to undertake actions aimed at protecting water resources and utilizing them efficiently. Sustainable water resource management is an approach that seeks to maintain a balance between available water resources and societal needs while ensuring the long-term protection of water system. This approach encompasses efforts to limit the excessive exploitation of water resources, develop and promote alternative water sources, as well as mitigating threats associated with change climate.

Sustainable water resource management requires employing an integrated approach that includes the needs of all stakeholders, including water users, governmental institutions, and local communities. The crucial role of educating children in the context of sustainable water resource management cannot be overstated. Teaching them to save water and reuse it stands as a milestone in their education. Children ought to learn methods of water conservation early on, both at home and in other public places, with this education continuing throughout their schooling. Another significant facet of educating children about sustainable water resource management involves nurturing pro-environmental attitudes. They should learn to respect water, appreciate its value, and comprehend the impact of their actions on the environment.

The paper presents the activities which were carried out as a part of the international project „waterCEmanagement in practice - developing comprehensive solutions for water reuse and raising awareness of the key role of water in the transformation process towards a circular economy (CE)" such as summer school, educational games and competitions. The goal of these activities was to educate children about water in the CE.

Keywords: education, water, Circular Economy, sustainable management, teaching children

Acknowledgements: The paper was prepared as a part of the project "waterCEmanagement in practice - developing comprehensive solutions for water reuse and raising awareness of the key role of water in the transformation process towards a circular economy (CE)" which uses funding worth 323 549,34 euro received from Iceland, Liechtenstein and Norway under the EEA Funds. The aim of the project is to strengthen the transformation towards a circular economy in the field of circular water resources management.

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Technological synergies for sustainable water and sewage management in Circular Economy

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Rapid advances in technology and rising environmental challenges call for the integration of artificial intelligence, digitization, and green open innovation into the Circular Economy (CE) to build a transformative pathway for sustainable development, particularly in water and sewage management. This research synergizes empirical findings that showcase the pivotal role of technology and innovation in enhancing CE performance in water resource management and waste reduction within the context of developing countries and associated global supply chains. First, this research explores the adoption of AI-based reverse logistics in Indian Micro, Small, and Medium Enterprises (MSMEs), underscoring its significance in facilitating and improving CE performance through efficient recycling and reuse practices. Using a structural equation modelling approach the adoption of AI-based reverse logistics to improve CE performance is analysed through the lens of natural resource-based view theory for optimizing water usage in production processes. Second, the digitization assisted CE within global supply chains is analysed to attain sustainability in global supply chain by identifying critical success factors using Grey Decision-Making Trial and Evaluation Laboratory method. Human centric sustainable operations towards CE and Process improvement and optimization through digitization are found to be the critical success factors in digitization assisted CE that drive sustainability and facilitate water conservation and pollution reduction. Further, this research investigates Green Open Innovation and CE with emphasis on the important role of Big Data Management and Sustainable Supply Chain Practices in achieving Circular Economy Targets, specifically through enhanced water management and pollution control strategies. A structural equation modelling approach reveals the positive association of big data management with knowledge management and big data capabilities. Understanding how technological and innovative practices address the challenges of water and sewage management within the CE model and thus this research provides valuable insights for policymakers, practitioners, and academicians striving for green deal strategies for sustainable development against the global environmental challenges.

Keywords: Circular Economy, artificial intelligence, digitization, green open innovation, sustainable supply chain, water management, waste reduction, big data management

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Carbon neutrality of wastewater treatment plants

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Decarbonization (or minimization of carbon footprint) is one of the most important challenges for the advancement of wastewater treatment plants (WWTPs). The first step towards achieving a net-zero carbon condition involves identifying emission hotspots and quantifying those emissions. In WWTPs with energy recovery, direct process emissions typically account for over 60% of the carbon footprint, with around 30% attributed to energy-related indirect emissions.

Nitrous oxide (N_2O) emissions receive particular attention due to their significant impact on the carbon footprint. Reports indicate high shares, exceeding 50% of N_2O emissions in the carbon footprint of biological nutrient removal WWTPs. Although current estimation methods rely on fixed emission factors, their practical applicability is hindered by high uncertainty. In contrast, mechanistic activated sludge models offer a robust approach to reducing the uncertainty of direct N_2O emissions and developing mitigation strategies.

Case studies from Poland and Finland show the diverse array of components contributing to carbon footprint. Differences in influent wastewater characteristics, treatment processes, and operational conditions between the two countries underscore the complexity of carbon footprint assessment in WWTPs. Notably, Polish WWTPs exhibit greater energy self-sufficiency, while Finnish plants face higher chemical consumption, shaping their respective carbon footprints.

Transitioning towards net-zero carbon conditions requires GHG mitigation through process modification and energy optimization. The adoption of novel anammox-based nitrogen removal processes, such as PD/A and DAMO/A, emerges as a particularly promising strategy to reduce GHG emissions and energy consumption while ensuring efficient nitrogen removal. Decarbonization efforts may thus contribute to advancing sustainable practices in WWTPs.

Keywords: carbon footprint, GHG emissions, nitrous oxide, wastewater treatment

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A virtual water and water footprint perspective of Circular Economy

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We need to track and measure water use throughout the economy to understand and address water insecurity. This is necessary to avoid shifting water scarcity risks to places with weak water regulations and creating an unrealistic impression of local water sustainability by keeping water-intensity activities out of sight. For instance, water use reductions in a city can be negatively offset by the water embedded or the virtual water associated with import products to the city. The virtual water and water footprint constructs provide a robust framework for developing reliable local to global water tracking and measuring tools by integrating advances in big data, network science, and artificial intelligence. In addition, this water analytics approach can also be used to understand and analyze how disruptions from extreme water-related events propagate across places through supply chain networks. Using the United States as an illustrative case, I review cases and examples that showcase the framework. A central conclusion from this work is that the circular water economy needs to be complemented with a circular virtual water economy; otherwise, we may run the risk of being locally 'sustainable' but globally wasteful. To meet global water sustainability goals, it is necessary to account for water use across economic sectors and spatial scales from municipalities to countries linked through complex supply chain networks.

Keywords: water footprint, virtual water, water insecurity, sustainability, global

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Removal of pesticides from water by low-cost adsorbents

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The paper discusses the use of various low-cost adsorbents for pesticide removal from water. The main aim is to provide a summary of recent information concerning the use of low-cost adsorbents.

Pesticides are chemical substances used mainly to kill or reduce unwanted pests or invasive plants. The main consumers of pesticides are most often farmers who apply pesticides to protect crops. Although the use of pesticides fulfils the required function, it negatively affects the environment and disturbs the natural balance of ecosystems. Pesticides and their metabolites cause pollution of soil, water, reduce biodiversity and contribute to reducing the population of some living organisms in nature. Pesticides not only affect the ecosystem and aquatic life, but also have serious effects on health of humans and animals.

Pesticides (depending on their properties and chemical structures) are partially or completely removed from water by physical, chemical, and biological processes. Among these processes, adsorption is the most promising process because of its cost-efficiency, high performance, and properties of easily recovered and reused by regeneration operation. The most used adsorbents include activated carbon, carbon nanotubes, biochar, graphene, bentonite, zeolite, kaolinite, and chitosan. The success of the adsorption depends on the properties of the used adsorbent (e.g., pore size distribution, particular size, functional groups), adsorbate (e.g., polarity, hydrophobicity, functionality, point of zero charge,) as well as on the properties of the solution from which pesticides are removed (e.g., temperature, ionic strength, pH).

Keywords: pesticides, low-cost adsorbent, adsorption, water

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Investigation of the potential benefits of humic fractions derived from sewage sludge for improving soil and plant health

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The advantages of adopting a circular bioeconomy include optimized resource use, reduced environmental impact, mitigation of climate change, decreased the reliance on finite fossil resources, and the valorization of by-products and waste materials from various sectors, thereby facilitating their minimization and efficient utilization. The present work concentrates on the recovery of humic acids (HAs) and fulvic acids (FAs) from thickened (TSS) and anaerobically digested sewage sludge (ADSS), with a specific focus on investigating their potential benefits for ameliorating acidic, organic matter-deficient soils and the growth of selected plants. As demonstrated, the TSS proved to be a much more valuable source of HAs and FAs than the ADSS, containing 42% more of these compounds. An evaluation of the elemental distribution on the surface of HAs and FAs isolated from TSS and ADSS, conducted by X-EDS, revealed that carbon and oxygen were the main components of the investigated samples, with proportions typical for humic substances (HSs). The impact of isolated HSs was found to be predominantly contingent upon their concentration and the specific plant species under evaluation. Nevertheless, all derived HSs exhibited a positive effect on the development of maize, garden cress, oats, mustard, radish, and vetch, particularly in terms of hypocotyl biomass gain. Interestingly, HAs showed superior efficacy in stimulating plant growth compared to FAs. It was also found soil amendment with 75 mg mL^{-1} HAs and 150 mg mL^{-1} FAs recovered from TSS resulted in a 11% increase in the functional diversity of soil microbial communities in both cases.

Keywords: fertilizing potential, humic fractions, sewage sludge, resource recovery, waste management

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The experience of implementing membrane techniques in the practice of the swimming pool branch

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Moving towards rational economy, optimization and sustainability, both water, sewage and energy management, are the basis for the economic development of the 21st century. Considering Poland is one of the countries with a high risk of water stress, the use of membrane technologies in highly water-consuming facilities seems to be a complementary solution to two environmental engineering problems identified in our country today - the need for rational water management and reducing the operating costs of public facilities. Membrane filtration allows to reduce the water demand, reuse different water streams and close the water and sewage cycle management within one system. The separation of pollutants by the use of membrane systems, together with the reduction of expenses on chemicals dosed for disinfection of recovered water and lack of transformation of pollutants constitute a significant and undeniable advantage for the discussed technology. The following paper aims in presenting the case study of two membrane filtration units installed in the swimming pool located in Poland. Analysis of water parameters before and after the membrane process, ease of operation, fouling effect, lifetime and ability to regenerate were a scope of this study. Selection of the appropriate system, control of filtration parameters, backwash, cleaning frequency and proper operation sequence allow for the most optimal work of the unit, with relatively highest operational profitability related to the need of replacement membranes in relation to the amount of water recovered.

Keywords: membranes, swimming pools, sustainability, water stress

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Comprehensive study on the efficient elimination of Alizarin Red S dye in water using an eco-friendly clay-chitosan composite: experimental and theoretical investigation

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Alizarin Red S, a commonly used dye in the textile industry, presents a significant environmental challenge when discharged without proper pretreatment. This research conducted a comparative investigation into removing organic compounds from the dye using composite-based clay chitosan as an exceptionally effective adsorbent for the anionic dye. Several characterization techniques, such as FTIR, XRD, and EDX, were utilized to uncover the physical and chemical properties of the prepared material. Key factors like adsorbent dosage, pH, reaction time, and initial concentrations were optimized in a batch system. The findings revealed that the optimal adsorbent dosage was 50 mg, resulting in maximum adsorption at a low pH. Equilibrium adsorption of the dye was achieved in approximately 12 minutes, with an optimal initial concentration of 30 mg/L. Additionally, the study discussed adsorption kinetics, isotherms, and thermodynamic parameters. The pseudo-second-order kinetic model accurately represented the reaction kinetics, while the thermodynamic data indicated an endothermic and spontaneous process ($\Delta H = 27.22$ kJ/mol, $\Delta G < 0$), suggesting favorability with increasing temperature. Furthermore, density functional theory (DFT) calculations were performed to elucidate the adsorption mechanism, highlighting the involvement of benzene rings and oxygen atoms in Alizarin Red S as electron donors and explaining the behavior of chitosan active sites with Alizarin Red S. The synergistic combination of chitosan and clay shows promise in the development of adsorbents that can effectively remove both anionic and cationic dyes from water treatment in future applications.

Keywords: adsorption, Alizarin Red S, Chitosan-Clay Composite, thermodynamic and kinetic study, DFT.

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The synthetic PFAS and selected EDCs in water and wastewater treatment – Cracow case study

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The dynamic development of industry, pharmacology and breeding causes: (a) an increase in pollution in rivers and water reservoirs, which are a source of drinking water, and (b) a deterioration in the quality of sewage flowing to the treatment plant.

The aim of this work is to screen water and sewage samples for the presence of synthetic per- and polyfluoroalkyl compounds (PFAS) and the endocrine - active compounds (EDCs) i.e. 17ß-Estradiol, Bisphenol A and Nonylphenol (listed in DWD Water Directive EU 2020/2184, December 23, 2020).

A series of tests were performed on drinking and raw water for four Water Treatment Plants in Krakow (Raba, Rudawa, Bielany, Dłubnia) for the presence of PFASs and EDCs. Trace response values were obtained and the concentration for the sum of all analyzed fluoroalkyl compounds was below the parametric value specified in the Directive of 0.1µg/l. No positive response values were observed for EDCs.

The direct and indirect protection zones of Krakow intakes were analyzed for the presence of selected EDCs. Only 1 of the 20 samples analyzed showed a positive result for BPA (1.5ng/ml), below the parametric value. EDCs were not present in the remaining samples. The results obtained from tests of water samples from all analyzed sources did not show any exceedances in terms of PFAS indicators and selected EDCs.

The analyzes of sewage from three Krakow Wastewater Treatment Plants (Płaszów, Kujawy, Bielany) were carried out. The presence of PFAS indicators and selected EDCs was observed in the analyzed sewage samples.

Keywords : PFAS, EDCs, water safety, wastewater

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Membranes modified with selected oxide materials: preparation and application in tetracycline removal

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Presented research are focused onto design and preparation of a new group of membranes as components of bioreactors intended for purification of water systems from organic pollutants. The nanofiltration membranes were prepared using different inorganic components - synthesized oxide materials (Al_2O_3; Al_2O_3-ZrO_2; Al_2O_3-WO_3), which have been expected to affect the structure and surface nature of membrane in order to avoid any technological problems such as e.g. biofouling.

A commercial MK ultrafiltration membrane was used for the modification (polymer PES; MWCO 30 000 Da; Synder™). The modification of the MK membrane included formation of a polyamide layer (based on piperazine) containing specific oxide materials (in the amount ranging 0.1-0.5%) via interfacial polymerization.

The removal tests were performed for two different water systems containing defined concentrations of tetracycline hydrochloride (TRC) at pH=8. The experiments were performed for initial aqueous TRC solution and leachates raising from a trickle bed reactor in which the same amount of TRC was dissolved in the aqueous medium. Filtrate flux varied from 50 to 183 dm^3/m^2 h (under filtration pressure 0.1 MPa) depending on the polymer matrix, while maintaining TRC retention – from 30 to 70%.

Keywords: bioreactor components, nanofiltration, modified nanofiltration membranes, oxide materials, tetracycline removal.

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Effects of calcium/iron oxide composites used for phosphorus removal from wastewater on plant growth in hydroponic and soil-based systems

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Phosphorus (P) is essential for agricultural production, with phosphate rock serving as the raw material for chemical P fertilizer. However, extensive fertilizer use has led to environmental pollution and eutrophication of freshwater and estuarine ecosystems. P runoff from agricultural and industrial sources, as well as wastewater, contributes to water pollution. Yet, these P-containing wastewaters can also be used as a secondary resource for P recovery, promoting a Circular Economy model and sustainability. The research aims to determine the effect of calcium/iron composites after application in P removal from municipal wastewater on seedling growth of common wheat (*Triticum aestivum*) and plant growth of faba bean (*Vicia faba*). The addition of saturated calcium/iron composites significantly enhanced the growth of wheat seedlings in hydroponic systems, with higher concentrations increasing total shoot length, shoot fresh and dry mass, and leaf water content. At a concentration of 250 g/L, there was a plateau in both shoot fresh mass and shoot length, with the second leaf reaching 135.4 mm, compared with 81.7 mm in the control group. Faba bean growth tests in greenhouse experiments revealed that adding saturated composites significantly increased soil pH, while concentration above 25 g/L reduced morphological and photosynthesis parameters of plant growth compared to control. In conclusion, P-saturated calcium/iron composites show potential as growth enhancers for plants, although further detailed research is necessary to determine the optimal application based on soil acidity, plant requirements for nutrients, and other relevant parameters.

Keywords: phosphorus recovery, soil amendment, nutrients, wastewater, mineral sorbent

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Geospatial and index analysis of water quality at municipal solid waste landfill sites: case studies

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The study presents an evaluation of water quality at selected Municipal Solid Waste (MSW) landfill sites in Poland and the Czech Republic by using the Water Quality Index (WQI), Landfill Water Pollution Index (LWPI), and Nemerow Pollution Index (NPI). Moreover, the study provides an investigation of various water quality parameters and their changes over time as well as their levels in relation to the standards set by environmental law. The study presents key contaminants and their spatio-temporal variations, emphasizing the critical need for proactive monitoring, reclamation measures, and strategic interventions. Groundwater monitoring results were analyzed to develop maps depicting the distribution of pollutants in groundwater and potential pathways of their migration in the vicinity of the landfills. The results indicate an improvement in groundwater quality over time which is an effect of the conducted reclamation efforts at the analyzed landfills. The findings of this study address current water quality challenges but also offer valuable guidance for future landfill management practices, emphasizing the significance of sustainable and informed decision-making in the landfill environment.

Keywords: water resources, pollution, chloride, waste management

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Microplastics in sediments a vector of aquatic pollution

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The growing demand for plastics is a noticeable problem, given the amount of plastics in the total mass of human waste. Large pieces of plastic can be partially removed from the environment, such as by segregation, while plastic pieces smaller than 5 mm, so-called primary or secondary microplastics, which are the result of degradation and fragmentation of larger plastic objects, not only contaminate the environment, but remain in it, as it is impossible to remove them effectively, especially from more complex environmental matrices such as sediments. Given the above and the fact that microplastics are quite persistent in the environment and do not easily biodegrade, they pose a huge threat not only to individual organisms, but can also contribute to the reduction of biodiversity and long-term disruption of ecosystems. Some of microplastics ends up in surface waters and then the seas and oceans. According to date given by some authors the number of microplastic particles in river waters is highest in estuarine sections and in highly urbanised areas and depends, among other things, on atmospheric conditions. Standing waters, i.e. lakes and reservoirs, are also exposed to microplastics pollution. Microplastics have also been determined in drinking water, both bottled and tap water. Drinking water is primarily contaminated with very fine plastic fractions of 5-20 µm. It is estimated that microplastics may be present in more than 90% of bottled water and in more than 72% of tap water samples. The aim of the study was to highlight the presence of microplastics in sediments as vector of aquatic contamination.

Keywords: microplastics, contamination, sediments, water

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Preliminary study on microplastics (<5mm) profile in sludge from water treatment plants

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Increasing amounts of plastic waste are raising concerns regarding the presence of microplastics (MPs) in aquatic environments. The study examined the occurrence of MPs in four water treatment plants (WTPs): Bielany, Dłubnia, Raba and Rudawa. Many MPs entering WTPs become trapped in the water treatment sludge (WTS), a by-product of the drinking water clarification process. According to regulations set by the Minister of the Environment regarding the R10 recovery process (January 20, 2015), WTS can be used on land, potentially serving as a source of MPs to the environment. Our research determined that the MPs content in WTSs ranged from 796 to 2,403 MPs/kg dry matter, with the lowest content found in WTP Bielany and the highest in WTP Raba. The isolated MPs underwent both physical and chemical analyses. The physical analysis, carried out using a stereoscopic microscope, enabled the visual identification of micropollutants. Additionally, it allowed for the determination of their size distribution (ranging from 1 µm to 1 mm and from 1 mm to 5 mm) and shape (fibers, foils, and fragments). Chemical identification was performed to determine the polymer type constituting the tested material. Fourier transform attenuated infrared spectroscopy (FTIR-ATR) was used for this purpose, and it confirmed the presence of PE, PES, nylon, and PP. Obtained results highlighted the need for the development of technologies to remove MPs and for improvements in WTS management.

Keywords: microplastics, water treatment plant, sludge from water clarification

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Application of the GC-MS/MS method for the determination of hydroxy derivatives of PAHs in sewage sludge

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Polycyclic aromatic hydrocarbons (PAHs) and their hydroxy derivatives (OH-PAHs) pose significant environmental and health risks because of their toxicity. These compounds are challenging to analyse due to their low concentrations in environmental samples and complexity of the matrices in which they are found, such as sewage sludge. In this study, gas chromatography tandem mass spectrometry (GC-MS/MS) technique was developed for the precise quantification of OH-PAHs in environmental sewage sludge samples collected from a wastewater treatment plant in Plaszow-Cracow. The most common in the environment: 1- and 2-Naphthol (1-OH-NAP, 2-OH-NAP), Fluoren-2-ol (2-OH-FLU), 9-Phenanthrol (9-OH-PHE), Pyren-1-ol (1-OH-PYR), and Benzo[a]pyren-3-ol (3-OH-BaP) were chosen as examples of the OH-PAH group. The determination method involved the extraction of QuEChERS from sludge samples, followed by derivatization for enhanced sensitivity and selectivity. Chromatographic separation was achieved using a GC column optimised for efficient resolution of analytes. Tandem mass spectrometry was used for sensitive and specific detection, utilising multiple reaction monitoring (MRM) transitions for each compound. The developed GC-MS/MS method was successfully applied, and the presence and concentrations were determined. The results revealed the levels of various OH-PAHs in environmental sewage sludge samples, providing valuable information to assess the environmental impact of sewage sludge disposal. In general, the proposed method offers a reliable tool for monitoring OH-PAHs in sewage sludge, contributing to the management of environmental pollutants and the protection of public health.
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Keywords: hydroxylated polycyclic aromatic hydrocarbons, sewage sludge, gas chromatography, tandem mass spectrometry, emerging contaminants

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Determining the possibility of using poor quality water from underground water intake protection well in water treatment technological processes: a pilot scale technological research

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The purpose of the research was to select an appropriate groundwater treatment technology, with particular emphasis on the possibility of using water from a protection well that is difficult to treat. Technological research was conducted on a pilot scale for 6 weeks. The pilot station was supplied with a mixture of water from a protection well and a primary well. The water from both wells was characterised by different physical and chemical composition. The installation of the pilot station enabled various configurations of technological processes and continuous water sampling before each technological device. During the technological process of water treatment, samples were taken and the following parameters were determined: temperature, pH, alkalinity, colour, turbidity, COD $KMnO_4$, TOC, dissolved oxygen, iron and manganese. On the basis of the analysis of the test results, it was found that the water treatment technology based on the processes of natural aeration and rapid filtration was effective in the case of a mixture of water taken from two wells. The quality of treated water was consistent with the requirements specified in the Regulation of the Minister of Health on the quality of water intended for human consumption. This solution made it possible to use water that would have to be captured, but was not used to ensure the efficiency and quality of the basic wells that supply the water treatment plant.

Keywords: groundwater, technological research, pilot scale, water treatment

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Reclaimed water reuse for sustainable resource management and phosphorous recovery

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Limited availability of freshwater resources on one hand, but increased water consumption and wastewater volumes on the other, requires development of new management practices and technologies of reclaimed water reuse and dissolved element (at first phosphorus) recovery. Reclaimed water reuse is an economically and technologically feasible water resource-saving approach and its application potential has been demonstrated worldwide as well as in the Baltic Sea region. To implement reclaimed wastewater reuse it is necessary to estimate the criteria of water flows, nutrients, pollutants, quality standards, size of facilities and other issues in water management systems. Therefore, the system boundary definition for wastewater reuse cases are a critical element considering local situation (topicalities, resources, and problems) as well as analysis of best-known technologies providing solutions for water reuse and recycling, especially concerning nutrient flows. Besides that, the research framework and procedures, including identification and description of analytical methods used, reporting and responsibilities of parties, and the technical set-up are of importance considering accepted legislation suggestions. Definition of system boundaries allow a more precise analysis of system efficiency and provide the opportunity to compare different water reuse options. This approach supports the selection of the best available technologies regarding environmental and economic factors. Another critical factor for reclaimed water reuse is related to legislative and institutional support as well as risk analysis results, identifying both environmental boundaries, economic feasibility analysis, societal acceptance and other factors to made water reuse efficient.

Keywords: reclaimed water, system boundaries, water reuse

Acknowledgments: Interreg Baltic Sea Region project ReNutriWater (No. #C016).

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Seasonal variation of physicochemical characteristic of wastewater form the Płaszów Wastewater Treatment Plant

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A significant problem for water management is municipal wastewater rich in biogenic elements. With the increasing development of urbanization, population growth, and intensification of agriculture, the amount of urban wastewater increases, and its composition deteriorates. Currently, urban wastewater is considered one of the main anthropogenic causes of eutrophication. The phenomenon of eutrophication itself leads to a number of negative ecological effects, such as changes in the species diversity of aquatic plants and animals or deterioration of water quality and requires measures to prevent its intensification. In the context of preventing the development of eutrophication, wastewater treatment plants play an important role, reducing the nutrient load in wastewater before it is discharged into water bodies. For this reason, the analysis of the composition of urban wastewater is an important topic of scientific research, necessary to ensure an effective and efficient treatment process.

The aim of the study was to determine the eutrophication potential of municipal wastewater from the Płaszów Wastewater Treatment Plant. The scope of the study included a comparison of the physicochemical properties of raw sewage and wastewater after the biological treatment process, calculation of the share of bioavailable forms of nitrogen and phosphorus in wastewater and assessment of the effectiveness of wastewater treatment at the Płaszów Wastewater Treatment Plant. Samples were collected from I 2020 to V 2022. The phenomenon of eutrophication and biogenic elements were discussed. The research part focused on the analysis of bioavailable forms of nitrogen and phosphorus in wastewater. Furthermore, the physicochemical properties of raw and biologically treated wastewater were compared, the change in selected properties depending on the season was investigated and the effectiveness of the wastewater treatment system in Płaszów was evaluated. The parameters analyzed were: pH, total suspended solids, BOD_5, COD, ammonium nitrogen, nitrate (III) nitrogen, nitrate nitrogen (V), total Kjedahl nitrogen, total nitrogen, orthophosphates, total phosphorus.

Keywords: biogenic elements, eutrophication, wastewater treatment

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Water reuse in the Baltic Sea Region – opportunities and risks

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Implementing the concept of water reuse is essential in regions with hot and dry climates. Still, it is becoming increasingly crucial for the Baltic Sea Region (BSR). According to the ReNutriWater project report (Klavins et al., 2023), BSR needs to develop water recovery because climate change harms the availability and quality of water resources. It is necessary to build awareness among interested parties about implementing Circular Economy principles in water resources management: recover valuable components remaining after wastewater treatment, at first, nutrients. The development of improved treatment technologies for effectively removing micropollutants is a condition for limiting the pollution of water resources.

Differences in consumption rates in BSR countries illustrate, on the one hand, the seriousness of problems with the availability of water resources, but on the other hand, the diversity of the problem. Therefore, some Baltic countries have launched projects involving efficient use of water resources and wastewater reuse options (water recovery, reclamation, and reuse). Since different wastewater quality, technologies, and pilot sites will be implemented, evaluating the criteria for water flow, nutrients, contaminants, quality standards, etc., in such systems is necessary.

So far, BSR countries have not implemented Regulation 2020/741 requirements for reclaimed water reuse. Most BSR countries are reluctant to actively implement reclaimed wastewater reuse and develop solutions for nutrient recovery from wastewater. However, bottom-up activities indicate that local actions can be effective.

The first results of preparations indicate opportunities for particularly vulnerable areas such as islands. On the other hand, wastewater treatment plant operators and municipalities are unprepared for such responsible undertakings, hence the need to develop guidelines and proceed in small steps.

Keywords: reclaimed water, water reuse, BSR, nutrient recovery

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The use of rainwater in swimming pool installations in accordance with the idea of a circular economy

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The circular water economy focuses on maximizing the use of water resources and reducing their impact on the environment. One of the most important components of this model is water resource recovery, involving treating water sources to restore its quality so that it can be reused. This approach promotes the conservation of water resources and reduces the necessity for new water sources, thereby reducing the environmental impact of water extraction. The concept of rainwater treatment and its use in swimming pools fits in with these assumptions. The work discusses the possibilities, risks, and limitations in this area. Analyses were carried out to estimate the volume of rainwater that could be used to supply selected swimming pool facilities. It has been shown that - provided rainwater is treated to the required quality parameters - it could be a source of water that will fully meet the demand of analyzed facilities for fresh water.

Keywords: rainwater reuse, water management, swimming pools, Circular Economy

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Review of methods for assessing water leaks in water supply network

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Reducing water losses in water supply networks is one of the most important challenges for water supply companies. The EU Directive 2184/2020 on the quality of water intended for human consumption introduces new legal regulations on the management of water losses for EU member states. They will apply to water supply companies that supply the water at level of 10,000 m3 /d at least or serve 50,000 people or more. By January 12, 2026, water supply companies should assess the size of leaks in water supply networks and the possibilities of reducing them. Directive 2184/2020 recommends the use of the ILI (Infrastructure Leakage Index) for this purpose. Then, by January 12, 2028, based on the results of the assessment of water losses in EU member states, the European Commission will determine the ILI values that water companies will be obliged to achieve and maintain. This work presents selected methods for assessing water leaks in water supply networks, such as: water balance according to IWA (International Water Association), MNF (Minimum Night Flow) analysis and the BABE method (Breaks And Background Estimates). A comparison of their methodology and the possibility of their application was presented. It is estimated that for Polish conditions, about 20% of water pumped into the water supply network is lost, generating operating costs for the company, which are then borne by consumers. Reducing water losses is consistent with the idea of the Circular Economy by optimizing the use of water resources in the water supply system.

Keywords: water losses, ILI index, MNF method, BABE method

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The application of microencapsulated active substances exemplifies an innovative solution that aids in reducing water consumption during the in situ bioremediation process of soils

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In situ bioremediation is a popular technique for restoring the biological equilibrium of contaminated sites. It is particularly used in areas with limited contamination spread, amid dense urban development, where soil removal would be a complex and expensive operation. Active in situ bioremediation methods include biostimulation and bioaugmentation.

Biostimulation involves the provision of nutrients to accelerate the growth and activity of indigenous microbial populations. Bioaugmentation, on the other hand, is a technique for enhancing the removal capacity of xenobiotics by introducing selected strains or bacterial consortia. In both cases, the introduced nutrients or bacterial consortia are in the form of aqueous solutions.

A few years ago, a solution emerged in the form of active substances immobilized in gel microcapsules. The use of this form of preparation has resolved several fundamental problems associated with the subsoil application of bio-solutions, including uncontrolled migration, leaching, and short lifespan. As a result, it has enabled an increase in the effectiveness of the process and a reduction in the total amount of water needed to achieve the same environmental effect.

Microencapsulated preparations act precisely where they are administered. They do not percolate deep into the soil profile and do not flow away with groundwater. They do not dissolve in water but decompose slowly, gradually releasing active substances. They do not leach from the soil during precipitation. They have increased resistance to soil stresses (excess or lack of water), serving as a reservoir of active microorganisms and nutrients. A single application of microencapsulated preparations is more effective than multiple applications of traditional bio-solutions, thereby saving significantly more water throughout the process.

This presentation showcases the results of several years of remedial work using microencapsulated preparations.

Keywords: bioremediation, soil, microencapsulation, environmental biotechnology

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The importance of photopolymerisation for the synthesis of polymeric materials for regenerative medicine

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The application of the closed-loop economy in the production of polymeric materials for regenerative medicine and tissue engineering offers significant benefits from both an economic and environmental point of view. The UV-field photopolymerisation method, enables the controlled synthesis of advanced biomaterials with diverse properties, with minimal raw material consumption and limited waste production.

The research focuses on the use of eco-friendly raw materials and the elimination of toxic solvents, with an emphasis on minimising environmental impact. In addition, it uses the photopolymerisation process in the synthesis of polymeric materials used in regenerative medicine and tissue engineering in the context of a closed loop economy. The impact of this method on the efficiency of biomaterial production is analysed, taking into account defined physical, mechanical and biological properties, including biocompatibility, degradation and ability to interact with tissues.

This study also assessed the environmental aspects of using photopolymerisation in the synthesis of polymeric materials, taking into account energy consumption, CO_2 emissions and the recyclability of materials. The potential of this method to reduce the environmental footprint of the biomedical materials industry by reducing waste and raw material consumption was indicated.

The presented study aims to highlight the importance of the photopolymerisation method in the synthesis of polymeric materials used in regenerative medicine and tissue engineering in the context of a closed loop economy. The potential of this technology to generate innovative solutions that are environmentally friendly, effective and safe for patients is highlighted, contributing to the sustainability of the biomaterials industry and environmental protection.

Keywords: photopolymerization, polymeric materials, closed loop economy, environment, regenerative medicine

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River Tawi: unveiling governance gaps and paving the way for sustainable water management through proactive reforms

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An examination of water management in the River Tawi region reveals shortcomings in governance standards and practices, hindering the ability to address existing and emerging risks while undermining institutional legitimacy. Drawing on the OECD's principles of good water governance and the rule of law, this study advocates for proactive reforms to strengthen governance structures, rules, practices, and participation. Neglecting these opportunities poses a significant threat to the sustainable management of River Tawi's water. Rather than reactive crisis-driven changes, our proposed reforms aim to establish continuous improvement processes for water governance, transcending mere transparency and accountability enhancements.

Keywords: River Tawi, rule of law, proactive reforms, water governance, and transparency

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Introduction to waterCEmanagement project - water reuse importance

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The implementation of the project "*Water-CE-management in practice – developing comprehensive solutions for water recovery and raising awareness of the key role of water in the transformation process towards a circular economy (CE)*" stems from the fact that water resources in Poland are among the smallest in Europe, and without taking specific measures to protect water resources against progressive climate change, the Polish economy may be significantly affected by water deficits in the future, which could negatively affect domestic agricultural and industrial production and the cost of drinking water.

The aim of the project is to strengthen the transformation towards a Circular Economy (CE) in terms of circular management of water resources. The project complements Poland's existing efforts in preventing and minimising the effects of drought, i.e., the Ministry of Climate and Environment (climate change adaptation programs, susza.gov.pl portal, etc.), the National Fund for Environmental Protection and Water Management, the Regional Funds for Environmental Protection and Water Management (My Water program), State Water Holding Polish Waters, National Centre for Research and Development, and many local governments offering subsidies for emerging retention systems. The need to develop water recovery and reuse solutions is also dictated by European law, which on 26.06.2020 approved a regulation on water reuse in the European Union (EU), as well as changes in wastewater directive, approved 10.04.2024. Therefore, the project is crucial for the possibility of adapting the Polish system to the EU requirements, as well as accelerating the transformation towards CE in the country. The implementation of the project is in line with the current CE documents at the national and EU level for the implementation of efficient management of primary (water) and secondary (recovered from wastewater and rainwater) raw materials, i.e. the Circular Economy Communications (COM 398,2014) and the European Green Deal strategy to eliminate water pollution (COM 640,2019), as well as the Polish CE roadmap. Moreover, this project complements the My Water program and the administration's drought prevention efforts. Further actions are necessary to achieve the ambitious transformation goals towards CE.

Keywords: water, wastewater, Circular Economy, CE, education, recovery

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Circular economy indicators in water sector

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Circular economy (CE) is a key area for implementing the green transformation, in line with the idea of the green deal, which in the European Union (EU) has adopted the framework of the "European Green Deal" striving for climate neutrality in 2050. In order to assess the progress of the green and circular transformation, it is necessary to define a set of indicators that should be dedicated to various sectors, including the water and sewage sector. The objective of this study was to propose a set of CE indicators that present environmental and technological aspects of water management in wastewater treatment plants (WWTPs). The list include among others: *i*) tap water consumption reduction; *ii*) wastewater generation reduction; *iii*) water footprint; *iv*) sewage sludge generation reduction; *v*) removal of pollutants from water; *vi*) removal of pollutants from wastewater; *vii*) water reuse; *viii*) water recycling; *ix*) energy recovery; *x*) resources recovery; *xi*) biogas production. The diverse nature of water and sewage enterprises (supplying water to the population, sewage treatment, recovery of raw materials and energy) causes difficulties in creating a uniform system for assessing the implementation of CE. Therefore, the presented of CE indicators is still open. The further research on water-related CE indicators is expected in coming years.

Keywords: water, sewage, Circular Economy, CE, indicators

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Photocatalytic activation of peroxymonosulfate: ciprofloxacin degradation through novel coupled system

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The presence of antibiotics in the environment constitutes a serious problem to human health and life. Wastewater treatment plants are considered one of the main sources of antibiotics. Therefore, the search for the most effective methods of wastewater purification is underway. The combination of photocatalysis and peroxymonosulfate (PMS) oxidation has attracted increasing attention over the past decades. Photocatalytic activation of PMS under visible light holds significant promise due to its economic, renewable, and environmentally friendly nature.

The aim of the study was to assess the removal efficiency of ciprofloxacin (CIP) by solar-driven photocatalysis using TiO_2 and ZnO. Tests were also conducted in the presence of PMS, which may improve oxidation efficiency by generating sulfate ($SO_4^{\bullet-}$) and hydroxyl ($HO^{\bullet}$) free radicals. The experiments were carried out in milliQ water (MW) and tap water (TW) spiked with 2 mg L^{-1} of CIP, photocatalyst concentrations of 20 mg L^{-1} each, and an PMS at two different concentration of 20 and 200 mg L^{-1}. Photolysis was performed in parallel with the photocatalytic experiments. Studies were carried out in a solar radiation simulator.

During all experiments, the concentrations of CIP were reduced to >90%. ZnO-based photocatalysis occurs more efficient in a more complex matrix, although TiO_2 demonstrated higher efficiency in degrading CIP in MW in the presence of SO_4^{2-}. Its efficacy is effected by the matrix complexity, presence of inorganic ions, concetration of PMS and the type of used photocatalyst. Solar-driven photocatalysis is a promising method to treat aquatic matrices from antibiotics.

Keywords: ciprofloxacin, peroxymonosulfate, photocatalysis, titanium dioxide, zinc oxide

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The role of retention reservoirs in the purification of contaminated river water for its safe reuse - the example of mountain areas in southern Poland

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Polish mountain regions are heavily burdened by tourism and are particularly oriented to water demand. Climate-neutral circular water management strategies can be applied in these areas. One of the examples is the retention of water in storage reservoirs. They collect water during its excess, retain for future reuse during shortage and potentially contribute to its purification from pollutants and micropollutants. The aim of this study was to determine if water retention in storage reservoirs allows to obtain water safe enough for further use in the irrigation of green areas in summer and the production of artificial snow in winter. The assessment was based on the presence and concentration of antimicrobials, antibiotic-resistant bacteria, antibiotic resistance genes, and bacterial community composition. Contaminated river water and water collected in a storage reservoirs in southern Poland were compared in terms of these micropollutants. Water retention in the storage reservoir nearly eliminated bacterial contaminants (e.g., *E. coli* numbers dropped from 350 CFU/100 ml to 10 CFU/100 ml), antibiotic-resistant bacteria, resistance genes (*blaCTX-M* and *ereA* present in river water and none detected in the storage tank), and antibiotics (clindamycin, enrofloxacin and trimethoprim present in river water, while only enrofloxacin detected once). Potentially pathogenic taxa, i.e. *Acinetobacter*, *Mycobacterium* and *Pseudomonas*, were also significantly reduced in the reservoir. Findings of this study may prove useful in risk management and prevention in wastewater reuse.

Keywords: antibiotics, antibiotic resistant bacteria, antibiotic resistance genes, mountain areas, storage reservoirs

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Remediation potential of Slovak phyllosilicates in removing potentially toxic metal elements from water

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Phyllosilicates represent one of the groups of layered clay minerals. In this study, we employed materials with montmorillonite, a layered clay mineral belonging to the smectite group, as remediation media. Its layers are formed by a single octahedral sheet sandwiched between two tetrahedral sheets, and the space between the layers is filled with exchangeable cations. Due to its layered structure and the negative electric charge on its surface, this mineral can effectively adsorb cationic forms of toxins from waters. The clay mineral Montmorillonite is a constituent of the rock bentonite.

Bentonites from the Central Slovakian deposits of Lieskovec, Hlinik nad Hronom, and Stará Kremnička were utilized as remediation media. To study the remediation properties of these materials, a series of laboratory adsorption experiments were conducted, using Cu (II), Ni (II), and Pb (II) as model ions of potentially toxic metal elements. The experimental results affirm the suitability of bentonite as a remediation medium for all the mentioned elements. The efficiency of remediation followed the order Pb > Cu > Ni. Based on the findings, it can be concluded that the observed remediation processes are rapid and spontaneous. Adsorption equilibrium is established within 20 minutes of contact between bentonite and the solution of the potentially toxic metal. The highest adsorption capacity (Q_{max}) was achieved by bentonite from the Stará Kremnička deposit for all used elements. The results of the experiments confirm the significant potential of bentonite for environmental use in remediating waters degraded by toxic loads from industrial or mining activities.

Keywords: water, remediation, clay, heavy metals

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Is it possible to achieve a positive energy balance at the wastewater treatment plant ? - research project employing the disintegration method

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The objective of the project is the analysis of the possibility of obtaining a positive energy balance by wastewater treatment plants through the application of pretreatment of sewage sludge before the stabilisation process in the digestion chamber.

The analysis will cover pretreatment in the form of the disintegration process implemented in two technological variants: separated disintegration and hybrid disintegration. Research on mesophilic digestion will be conducted with the application of AMPTS (Automatic Methane Potential Test System) in a continuous culture mode, permitting detailed determination of the digestion time and identification of the potential phenomenon of process inhibition. The project will cover the analysis of the rheological properties of raw sludge (before pretreatment) and sludge disintegrated in different variants and digested sludge, as well as the dewatering properties of digested sludge, allowing for the analysis of the effect of the applied pretreatment on the functioning of the entire technological system, including the energy management of the wastewater treatment plant.

Conducting such complex research will be possible due to combining the scientific potential of the project contractors specialising in particular areas, i.e. technology of sewage sludge management, with particular consideration of its disintegration process, flow rheology and hydraulics, and calculation of the energy consumption of technological processes.

Keywords: anaerobic digestion, sludge pretreatment, sludge disintegration, energy balance, renewable energy

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Educational and information campaign as a tool to strengthen progress towards circular economy (CE) in the water and sewage sector

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European policy regarding the transformation of various economic sectors towards a circular economy (CE) has been going on for many years. In the context of water and sewage management, the transformation towards the CE model takes into account, among others, more rational methods of managing water (as a primary raw material) and its reuse. Awareness and appropriate education of society in this area is one of the key factors supporting the transition to a more sustainable economic model.

As part of the international project „waterCEmanagement in practice - developing comprehensive solutions for water reuse and raising awareness of the key role of water in the transformation process towards a circular economy (CE)", a long-term information and educational campaign was carried out to deepen knowledge various stakeholder groups (general society, children and youth, scientists and young scientists, specialists and entrepreneurs) in the field of economical and sustainable management of water resources.

The article presents the implementation of an information and educational campaign, which was carried out based on modern educational tools, organising workshops - 7, training courses - 5, seminars - 3, educational games - 2 and a summer school - 1, also online. It should be emphasized that the selection of the right topic, education method and qualified specialists guarantees obtaining knowledge at a high level. Shaping ecological awareness through the education of various stakeholder groups is crucial to adapting the water management system to the requirements of the European Union.

Keywords: education, information campaign, Circular Economy, water, sewage

Acknowledgements: The paper was prepared as a part of the project "waterCEmanagement in practice - developing comprehensive solutions for water reuse and raising awareness of the key role of water in the transformation process towards a circular economy (CE)" which uses funding worth 323 549,34 euro received from Iceland, Liechtenstein and Norway under the EEA Funds. The aim of the project is to strengthen the transformation towards a circular economy in the field of circular water resources management.

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Supervision of materials come into contact with water intended for human consumption in the light of new EU legal regulations in relation to the circular economy

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In 2020, a new directive of the European Parliament and of the Council on the quality of water intended for human consumption entered into force. Among many very important changes regarding others: method of supervising water quality, based on risk analysis, Article 11 includes provisions regarding the unification of regulations regarding the admission to the market of materials in contact with drinking water. According to the provisions of this article, these materials cannot (a) directly or indirectly compromise the protection of human health as provided for by this Directive; (b) adversely affect the colour, odour or taste of the water; (c) enhance microbial growth; (d) leach contaminants into the water at levels that are higher than necessary in view of the intended purpose of the material. In accordance with the provisions of the Directive, in January 2024, the first EU implementing acts were created, containing a list of materials, compositions and ingredients approved for contact with drinking water, as well as methods for testing and approval of final materials in contact with drinking water, including specific migration limits. In parallel with the work on the Directive on the quality of drinking water, work was underway in the EU on other important legal regulations, the content of which included: directly translates into the market for trading materials used in contact with drinking water, which in turn is broadly related to the circular economy action plan adopted by the EU. According to the basis of the circular economy concept, all elements of the production chain: products, materials and raw materials remain in circulation as long as possible, while the generation of waste should be limited to a minimum. One of the materials in contact with drinking water that is worth special attention in the above-mentioned area, there are PVC pipes, widely used in water supply systems in Poland. According with the adopted EU policy, producers will be able to use recyclate of old PVC pipes for the production of PVC pipes, in accordance with the circular economy. Unfortunately, in the old technology of their production, lead was used, so there is a fear that the newly produced pipes will not guarantee full safety for water consumers in terms of the concentration of this element in drinking water. The article presents a detailed analysis of the above-mentioned.

Keywords: water quality, materials destined into contact with water

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Co-digestion of sewage sludge and biowaste for biogas production, GHG avoided emissions and profitable carbon credit development

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This study explores the potential of co-digesting sewage sludge and biowaste for biogas production, emphasizing carbon credit calculation and offset project development. In Estonia, where biowaste comprises a significant portion of municipal waste, efficient waste management strategies are essential. Co-digestion presents a promising avenue to enhance biogas yield and reduce greenhouse gas emissions.

Through a comprehensive life cycle assessment, we evaluated the environmental impacts of the co-digestion process. Despite identified challenges, such as higher emissions compared to similar studies, our analysis highlights the importance of utilizing biogas for heat and power cogeneration to minimize environmental burdens. In Narva City, 20,401.08037 m3/year of biogas was produced in 2012, facilitating the generation of electricity from renewable sources and thus reducing GHG emissions, which facilitates the calculation of carbon credits.

In this study, sewage sludge was effectively utilized as a co-feedstock for the co-digestion process, contributing to increased biogas production. We developed a robust carbon offset project based on the biogas volume, meeting additionality criteria and demonstrating long-term benefits. The revenue potential from carbon credits ranged from 118 EUR to 41300 EUR, depending on market prices and project attributes.

Moreover, the offset project and calculated carbon credits offer tangible benefits to sustainable waste management and the implementation of the circular economy. By valorizing sewage sludge and biowaste through anaerobic digestion, the project contributes to waste diversion from landfills, reduces methane emissions, and promotes renewable energy generation. This integrated approach aligns with principles of sustainable waste management and supports the transition towards a circular economy model. Our findings provide valuable insights for policymakers and stakeholders interested in leveraging anaerobic digestion for renewable energy production and carbon mitigation.

Keywords: co-digestion, biogas production, carbon credits, renewable energy, Circular Economy

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The Circular Economy millstone on water recycling reclamation and reuse literature

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Articles studying water recycling, reclamation and reuse have been analysed in relation to article type, topics, country of origin and circular economy (CE) relevance. Findings are based on Scopus database search. 18.7% of the CE published journal papers on the studied keywords, are review papers, more than double compared to articles without mention on CE. Most review articles on CE come from India, Italy, UK and Spain, while most research articles on CE come from Spain, Italy, China and UK. The share of non-technical articles on water recycling reclamation and reuse is higher when circular economy is studied; 5.02% vs 2.20% for social sciences, 4.11% vs 1.35% for Business management and accounting and 2.55% vs 0.65% for Economics, Econometrics and Finance. Although water has been researched for decades, from the environmental, engineering and energy disciplines, the green deal and circular economy has helped advancing the research from other disciplines also leading a more holistic and sustainable consideration.

Keywords: Circular Economy, green deal, reclamation, recycling, reuse

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Biomethane potential of post-processing liquid from the hydrothermal carbonization of sewage sludge

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Hydrothermal carbonization is a good option for sewage sludge management, because it decreases the quantity of sewage sludge, enhances its dewaterability, effectively removes water, microplastics and pharmaceutics, and ensures complete sludge hygienization by deactivating viruses and bacteria. However, the weak point of this technology involves disposal, which results in a high quantity liquid phase. Hydrothermally carbonized wet sewage sludge transforms through thermochemical reactions into a liquid-solid slurry. During this conversion most of the organic compounds transfer from a solid to a liquid phase, which is highly organic. Consequently, there is an opportunity for biomethane production. In this work, the post-processing slurry (liquid-solid phase) and the filtrate, received through the vacuum filtration process, were investigated under the conditions of a biomethane potential test using AMPTS II (Automatic Methane Potential Test System) from Bioprocess Control. In addition, the chemical oxygen demand was determined for both samples. Furthermore, the post-processing filtrated liquid was analyzed in terms of its chemical and physical properties employing a spectrophotometric method. In brief, the filtrate exhibited a higher biomethane potential in a shorter retention time.

Keywords: sewage sludge, hydrothermal carbonization, post-processing liquid, biomethane

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State-of-the-art in the protection of the environment against microplastics pollution – removal technologies vs. prevention at source

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The revision of the Urban Wastewater Treatment Directive tends to protect human health, making the treatment process more cost-effective and energy-neutral and resulting in better quality effluents that can be reused. Among others, new standards for the concentration of micropollutants have been proposed. One of the new pollutants that will be necessary to monitor is microplastics. Monitoring the water environment's pollution with microplastics is important, but this approach underlines the need for treatment technologies to reduce concentrations. Less attention is paid to decreasing the pollution of influents by the primary and secondary microplastics. Some countries, such as, e.g. the United States, have set regulations banning the production and use of cosmetics containing microplastics. The area that needs to be taken care of more is, however, the education of the citizens on the effects and threats connected with the discharge of these pollutants, e.g., with washing machines' effluents. No central and planned politics are involved in decreasing the discharge of microplastics to severe systems. No strategies for microplastic management are planned. The present study aims to present the state of the art in the available technologies of microplastic removal from effluents during quaternary treatment. This approach is compared to the prevention technologies at the source. Pros and cons of the approaches and technologies are presented and discussed. Based on the comparison, the main areas of preferred approaches are proposed, including education strategies and technological challenges.

Keywords: microplastics, quaternary wastewater treatment, micropollutants, Urban Wastewater Treatment Directive

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Wastewater management and environmental protection

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Almost half of residential buildings in Poland are not connected to the sewage system. Over 10 million people have to use cesspools and on-site sewage treatment plants. The lack of sewage connection is not only a Polish problem; in the United States 83 million people are not connected to the sewage system, and in Europe it's as high as 112 million residents. The issue related to underdeveloped sewage systems is a global concern.
Key to an efficient system of managing transported wastewater are wastewater discharge point stations. Unfortunately, most of them face technological delays and do not meet the requirements of the regulation issued by the Minister of Infrastructure on October 17, 2002, regarding the conditions for introducing wastewater into wastewater discharge point station.

The solution to the problems faced by wastewater discharge point stations is the digitization of wastewater management. Modern IT solutions allow for the sealing of the transported wastewater circulation, as well as real-time monitoring of wastewater treatment plants and immediate response to irregularities. Thus, they significantly contribute to environmental protection.

We are coming with wastewater.cloud - the most advanced system dedicated to wastewater treatment plants, designed for comprehensive management of the wastewater discharge point station. Using the wastewater.cloud system enables wastewater treatment plants workers to continuously monitor discharges made by wastewater tanker drivers with whom the plant has a contract. Detailed monitoring of each discharge occurs in real-time, allowing for fast action in case of any irregularities.

Keywords: wastewater, transported wastewater, digitization of wastewater system

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Water recovery in a wastewater treatment plant and the importance of this object in the water and wastewater cycle in smart cities

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Current technological challenges for the development of wastewater treatment plants are aimed at recovery of water from wastewater, reduction of fresh water consumption, minimization of the "ecological footprint" and energy self-sufficiency. In terms of water recovery from wastewater, this involves using treated wastewater for technological purposes in the wastewater treatment plant and for other purposes in the agglomeration (smart cities). Thus, wastewater treatment plants are objects where the water cycle is applied and also objects that are in the water and wastewater cycle in the urban agglomeration (smart cities). The use of recycled water from wastewater for technological purposes in the treatment plant is to direct it to the following purposes: washing of screenings separated on grids, washing of sand from sand traps and washing of sludge dewatering equipment. This allows for significant savings in fresh water consumption.

Applications of treated wastewater in the agglomeration are follows: using it for irrigation of energy crops and for technological purposes in factories. The issue of water recovery from wastewater and the proper use of treated wastewater is timely and important in the context of cooperation between science and business. Scientific technological solutions can be the basis for the application of additional treatment processes that will allow wider use of reclaimed water. Implementation of scientific solutions in agglomerations (including smart cities) requires support from business, so cooperation between science and business is very important issue.

Keywords: wastewater treatment plant, recycling, water reuse, smart cities

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New solution for phosphorus recovery in circular water filtration systems

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Phosphorus is one of the key raw materials for the global economy, playing a crucial role in maintaining food production levels that meet the nutritional needs of most developed economies. Therefore, its deficit or limited availability should be considered a significant threat to contemporary civilization. As a member of the European Union, Poland is among the economies dependent on phosphorus imports. This means that the implementation of new solutions aimed at recovering this element from secondary sources, such as wastewater discharge from sewage treatment plants or retained water from agricultural fields, could prove key to improving national resource security.

The aim of the conducted research was to determine the efficiency of new filtration beds based on a mixture of limestone and silicon based minerals, allowing for the selective binding of phosphorus compounds. The developed beds are designed for both active and passive filtration systems and can be adapted to support the fourth stage of sewage treatment or for use in independent systems for the purification of retained, rain, or even grey water. The concept of the developed solution involves: binding of phosphorus at the water filtration stage, processing the bed after the end of its exploitation, and using the obtained material as a stabilizer for organic waste (sewage sludge, post-fermentation) for fertilizer production. This approach fits within the circular economy policy agenda and, in an economic context, can serve as a form of compensation for the costs arising from the application of an additional water purification stage (in the form of filtration beds with the discussed characteristics).

The results allowed for observations indicating the effectiveness of phosphorus recovery at a level of 45-71% in active systems and 61-84% in passive systems. The analysis was conducted under ex-situ conditions on an experimental installation consisting of flow-through filtration chambers. Based on the obtained data, it can be stated that the practical use of beds with the tested specificity may prove to be a good solution in the design of new systems for water purification.

Keywords: water filtration, filtration bed, 4’th stage in wastewater treatment, filtration method

Acknowledgments: The project “waterCEmanagement in” uses funding worth 323 549,34 euro received from Iceland, Liechtenstein and Norway under the EEA Funds. The aim of the project is to strengthen the transformation towards a circular economy in the field of circular water resources management.

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Circular economy- risk of using fertilizer produced from sewage sludge

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The circular economy is a developing area of science. Rational use of unnecessary products is key to minimizing waste and relieving the environment. This idea includes the production of fertilizer from sewage sludge, an unnecessary product of sewage treatment. It is important to pay attention not only to the benefits but also to the dangers of such use. Before being released into the environment, such a product should be thoroughly tested; unfortunately, there are no standards for some contaminants that can be referred to. One such pollutant is microplastics.

The research aimed to analyze fertilizer produced from stabilized sewage sludge collected during the summer months. The analysis was carried out in terms of microplastic content. Fertilizers were first freeze-dried. Microplastics are then separated using hydrogen peroxide (H_2O_2) and a saturated solution of calcium chloride ($CaCl_2$). The microplastics were weighed and counted and an identification analysis was performed. For this purpose, a confocal Raman microscope was used.

The average microplastic content from June samples is 220 fractions per 100 grams of dry fertilizer. In the case of July samples, the average microplastic content was 183 particles. Microplastics were also analyzed in terms of size and qualitative composition. Microplastics range in size from several hundred micrometers to over 5,000. The dominant source of microplastics was polyethylene. Studies clearly show a significant risk of microplastic contamination when using fertilizers made from sewage sludge. With a standard application of 500 g of fertilizer per 1 m^2 of land surface area, there is a risk of emission of approximately 915-1100 microplastic particles.

Keywords: microplastic, sewage, fertilizer, contamination, spectroscopy

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Reduction of nitrogen compounds and hardly decomposable organic compounds using a deep oxidation process

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This paper presents the application of the Advanced Oxidation Process (AOP) method for the removal of nitrogen compounds and dissolved, non-biodegradable organic compounds (COD_{TRNB}) from wastewater. The method used in this study consisted of dosing hydrogen peroxide H_2O_2 into the wastewater in the presence of UV light. Under UV light, highly reactive hydroxyl radicals OH* are released, which cause the destruction of even the most stable chemical bonds present in organic compounds.

The research was carried out on a semi-technical scale in a semi-automatic plant with a capacity of 0.5 m^3/d. Wastewater from food processing plants, car washes and leachate from the dewatering of excess sludge from municipal wastewater treatment plants were tested. A 90% reduction in organic carbon and nitrogen compounds in the effluent and dewatering leachate was achieved during the study. As a result of the deep oxidation process used, the BOD_5/COD ratio was changed. An additional benefit of the AOP process was the reduction of odour emissions from the plant.

Keywords: Advanced Oxidation Proces, UV light, hydrogen peroxide, wastewater

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Chemical indicators of swimming pool water ageing

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The issue of pool water ageing relates to the deterioration of water quality during its retention in the pool basin and in the closed cycle of its treatment. The ageing of pool water is related to the concentration of dissolved pollutants in it. This, in turn, depends on the need for water (usually tap water) to make up the losses, the water treatment technology, the type of pool and the load of bathers. Based on the results of water quality analyses of water samples taken (daily for three weeks) from two sports pools (outdoor and indoor) with similar technical characteristics, treatment technology and circulation water retention time, the problem of pollutant concentration in pool water is presented. The chemical indicators that were used to monitor the ageing of the pool water were total organic carbon (TOC), combined chlorine, nitrates and chlorides. Exceeding the permissible values of pool water quality indicators suggests the need to refresh the circulating water. In the case of the outdoor pool (OP), due to its characteristics and the constriction of TOC (> 4 mg C/L), combined chlorine (> 0.3 mg Cl_2/L), nitrate (> 20 mg NO_3^-/L) and chloride (> 250 mg Cl^-/L) occurred much faster than in the indoor pool (IP). The adopted schedule for washing filter beds (every three days) and the subsequent supplementation of the circuits with tap water had the effect of reducing the concentrations of the indicators analysed. However, supplementing the circulation of the OP with a volume of water 38 m^3 (the required minimum is 40.5 m^3) was insufficient to achieve a long-term effect of water refreshment. In turn, supplementing the circulation of the IP with a volume of 30.5 m^3 (the required minimum is 22.5 m^3) was entirely sufficient and indicates that it is possible to reduce the volume of water used to wash the filter beds without having a negative impact on water quality. It was found that in order to assess the qualitative condition of the pool water, parameters such as TOC, combined chlorine, nitrate, and chloride can be considered as indicators and, depending on their amount, replenish the circuits with fresh tap water.

Keywords: aging of swimming pool water, water quality indicators, nitrates, chlorides, combined chlorine

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Energy recovery from waste activated sludge and food waste: Focusing on valuable chiral lactic acid and medium chain fatty acids

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The co-fermentation of waste activated sludge (WAS) and liquefied food waste (FW) into valuable chiral lactic acid (LA) and medium chain fatty acids (MCFA) is within a bio-based circular economy concept. On the one hand, under the optimum volatile suspended solid ratio of WAS and FW (6:1), LA production was observed under mesophilic fermentation of weak alkaline conditions (25.5 g COD/L) or thermophilic fermentation of neutral conditions (21.0 g COD/L). Key lactic acid bacteria such as *Bavariicoccus, Bifidobacterium, Dysgonomonas, Alkaliphilus, Streptococcus, Lactococcus, Enterococcus,* and *Corynebacterium* could be enriched with ammonia addition. To get the chiral LA molecule, the amendment of zero-valent iron could increase the optical activity of D-LA (6.4-fold versus the Blank), and salinity control at 30 gNaCL/L could achieve optical pure L-LA production. In addition, a high production at 52.7 gCOD/L was observed when granular consortia were employed. On the other hand, distiller yeast is adopted as inoculum, which introduces ethanol-producing yeast, such as *Wickerhamomyces* and *Saccharomycopsis* to the fermentation system. This leads to endogenous ethanol production (14.9 g COD/L) and enrichment of MCFA-producing bacteria (total 6.9%), finally achieving a high production of MCFA at 22.3 g COD/L (approaching the maximum solubility in water). During this process, the production of MCFA increased linearly (R^2 = 0.82) with the rising D-lactate content. This study provides a novel way to recycle LA and MCFA from organic streams.

Keywords: energy recovery, waste activated sludge, food waste, lactic acid, medium chain fatty acids

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Exploring the impact of biochar utilization on bioindicators: a comprehensive analysis

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Biochar, a carbon-rich material, which is obtained by the pyrolysis of biomass, has shown great promise as a remediation and soil enhancement agent. This abstract explores the complex link that exists between the application of biochar and how it affects bioindicators across a range of ecosystems and biomes. Bioindicators are sensitive markers of ecological balance and environmental health that are becoming more and more popular. They provide information about the sustainability and effectiveness of biochar-based interventions.

This abstract emphasizes the wide range of bioindicators used in many situations, such as soil microbial populations, plant development parameters, and soil chemical characteristics, by means of an extensive assessment of recent research. Moreover, it investigates the complex processes by which biochar influences biotic and abiotic elements, influencing the dynamics and functionality of ecosystems. The impact of biochar on the diversity, abundance, and activity of bioindicator species highlights the material's ability to support robust and long-lasting ecosystems.

This abstract also explains the wider environmental effects of applying biochar by going over how it affects soil carbon sequestration, greenhouse gas emissions, and nutrient cycling. This abstract provides insights into future options for improving the use of biochar as a tool for fostering environmental sustainability and resilience by integrating existing information and identifying research needs.

Keywords: biochar, bioindicators, environmental effects, ecosystem resilience, sustainability

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