forum 94

Newsletter of the Chair of Urban Water Systems Engineering

ANNUAL REPORT OF THE CHAIR OF URBAN WATER SYSTEMS ENGINEERING

2023

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Foreword

Dear friends of the chair,

An eventful year 2023 has come to an end: a year with many changes and a year in which continuous global change became apparent. We live in a changing world. Droughts, forest fires, heavy rain and also groundwater reserves that have been filled again in Germany - at least temporarily - shape our image of the changing water cycle. With the attack on Israel, which is to be condemned in the strongest possible terms, and the subsequent military operation in Gaza, a new, flaring source of crisis emerged in the Middle East, which further destabilized the world political situation.

Nevertheless, we are very grateful for the productive year at the chair and that we were able to continue our important activities on adapting to the climate impacts of a changing water cycle.This year our employees were very active in publishing their scientific findings and sharing them with the national and international research community at conferences and lectures.

We are happy for Dr.-Ing. Carolina Feickert Fenske, Dr. rer. nat. Julia Reichel, Dr.-Ing. Michele Ponzelli and Dr.-Ing. Philipp Sperle, who successfully defended their doctoral theses this year. Special congratulations go to Dr. Thomas Lippert, who received the Willy Hager Prize 2022 for his doctoral thesis, to Dr. Christoph Schwaller, who received the TUM Civil and Environmental Engineering Department Prize for his doctoral thesis, and to Dr. Pablo Vega Garcia, who received the Mall Environmental Water Prize for outstanding dissertations. Congratulations! I am also pleased that I was awarded the Bavarian State Medal for outstanding contributions to the environment.

In 2023 we celebrated an important anniversary. We organized the 50th Wastewater Technology Seminar (ATS) as a two-day conference in July in the Science Congress Center at the TUM Campus Garching. The 50th ATS anniversary was an opportunity to review and assess developments in the fields of drainage systems, rainwater management, biological wastewater treatment and further wastewater treatment, automation, resource recovery and water reuse over five decades with selected leading experts and the interested professional public, which trends and recommendations can be derived for the entire wastewater sector in the future.

In our 'core business', the chair again made significant contributions last year to the training of students in the bachelor's degree programs in Environmental Engineering and Civil Engineering as well as in the master's degree programs in Environmental Engineering, Civil Engineering and Sustainable Resource Management. In addition to a large number of lectures, exercises and internships, the chair's staff supervised numerous master's theses, theses and bachelor's theses.

In addition to my teaching duties, as Academic Program Director I am responsible for the environmental engineering course and its further development at TUM and I continue to be involved in the International Water Association (IWA) and as a member of the Federal Government's Scientific Advisory Board for Global Environmental Change (WBGU).

On behalf of my employees, I would like to thank you very much for your support and your interest in our students and our work. We would also like to thank in particular for the support of our support association, which makes a very important contribution to the training of our doctoral candidates and students by financing trips to participate in conferences and grants for research work.

I am very pleased to be able to present you with this edition of our 2023 annual report to give you a small insight into our activities. In 2023 we were also strengthened by new employees, who will introduce themselves to you with their other colleagues in this annual report.

We would be very happy if we could provide this support for our doctoral candidates and students through your donation again this year.

We wish you a lot of confidence, a successful year and lots of reading pleasure

Yours,

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Research Center

The mission of the research center at the Chair of Urban Water Systems Engineering, directed by Prof. Brigitte Helmreich, is to provide support for process validations for both drinking water and wastewater treatment technologies at laboratory and pilot scale. In addition, we are conducting studies on new materials and processes and support research and development in close collaboration with industry partners, small and medium-sized enterprises, and public as well as regulatory agencies. The research center is comprised of a 400 m² pilot-scale facility and an adjacent research field, both with direct access to treated wastewater from the Garching Wastewater Treatment Plant (30,000 PE). This infrastructure enables us to conduct studies not only with drinking water but also to examine wastewater processes fed continuously with differently treated effluent qualities. For these studies, we can conduct experiments at laboratory and pilot scale with reactor volumes between 30 and 800 L in size. This provides opportunities to upscale and validate processes from laboratory to demonstration scale. Besides Zahn-Wellens-Tests to examine the biodegradability of wastewater samples (following DEV L 25), we also conduct activated sludge simulation tests (following DEV L 41).

Figure 1. Pilot-scale nanofiltration test skid (80 L/min).

Regarding advanced water treatment processes, the research center is equipped with test skids for chemical oxidation (ozone, UV irradiation with hydrogen peroxide, electrochemical oxidation) and membrane filtration (ultrafiltration, nanofiltration, reverse osmosis) (Figure 1).

In addition, the center is investigating and advancing treatment processes for urban stormwater and street run-off. For these investigations, we can utilize laboratory-scale test and soil column experiments of various sizes to examine the fate and transport of heavy metals and organic contaminants. Regarding urban run-off from copper roofs, a demonstration-scale test bed is available at the center, which is comprised of a large-scale copper roof and associated sampling and monitoring devices.

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Physicochemical, Trace Compounds Analysis, and Microbiological Laboratories

A central facility of the chair and the research center is the affiliated laboratory, divided into three areas: the physicochemical laboratory led by Dr. Carolin Heim, the trace compounds analysis unit led by Dr. Ignacio Sottorff and the microbiological laboratory led by Dr. Christian Wurzbacher.

The physicochemical laboratory is equipped with state-of-the-art analytical apparatus for the investigation of all relevant standard parameters in drinking and wastewater. Besides the characterization of water samples through sum parameters, such as COD and BOD, organic parameters can be further determined using 3-D fluores-cence and UV spectroscopy and measured quantitatively with the TOC analyzer. Determination of anions is carried out either using photometric test methods or through ion chromatography. For the analysis of metals atomic absorption spectrometry is available with flame and graphite furnace AAS as well as highly sensitive ICP-OES.

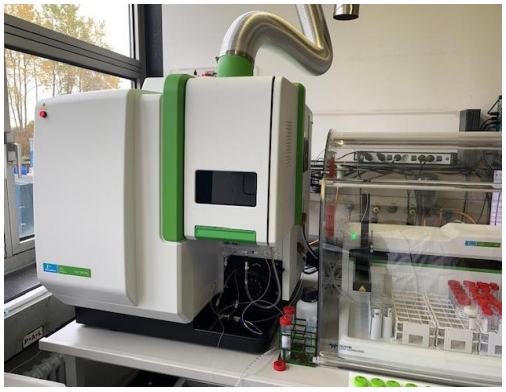

Figure 2. Determination of heavy metals using ICP-OES by Perkin Elmer.

The analytical laboratory is specialized on the characterization and identification of organic molecules from aqueous samples with trace compounds analysis (target screening), including perfluorinated alkylic acids (PFAS), using chromatographic separation techniques coupled to highly sensitive mass spectrometric detection techniques (LC-MS/MS). Volatile organic compounds, such as plasticizers or volatile fatty acids can be detected with the help of headspace-GC/FID as well as particles originating from micro plastics using a thermal desorption-pyrolysis-GC/MS, respectively.

Figure 3. LC-QTRAP-MS system by AB Sciex for trace analysis

The microbiological laboratory uses conventional techniques to determine the fecal indicator germs relevant for hygienic water quality. For disinfection experiments, we offer biodosimetry and direct detection of damaged microorganisms. Bacterial cell counts and antibiotic resistance genes are additionally quantified molecularly (quantitative PCR). High throughput sequencing technologies are used to characterize microbial communities.

Figure 4. Left: PCR and qPCR system to amplify and quantify different genes of interest. Right: microbial cultures for experiments.

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Research Group Drainage Systems

This year, the topic of "water-aware settlements" was also a priority in the drainage systems working group. Climate change poses significant challenges for urban drainage due to the increasing frequency of extreme weather events, such as heavy rain events and periods of drought. Therefore, adaptation strategies as a reaction to the consequences of climate change are becoming more and more critical. Integrate all actors of the grey, green, and blue infrastructure into the planning right from the start when new planning or the densification of districts in settlements takes place. Additionally, pollutants must be removed from the stormwater runoff of urban areas to prevent them from entering groundwater and surface water.

Figure 5. Pilot tests on biodiversity in the project Multifunctional infiltration swales in residential areas in Pfaffenhofen.

In 2023, we completed our research project "Multifunctional infiltration troughs in residential areas. The results will soon appear in a guide. Lots of information about biodiverse planting is given here. Plants in infiltration troughs must withstand waterlogging, extended dry periods, and road salt. Adapted planting will also be an issue in 2024 to respond to the consequences of climate change. Additionally, next year, we will continue to focus on pollutants from precipitation runoff, particularly pollutants in runoff from non-metal roofs. For this purpose, we were approved for a new research project.

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BAVARIAN ENVIRONMENT AGENCY (LFU),
BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION (STMUV)

COLLABORATION:
WEIHENSTEPHAN-TRIESDORF UNIVERSITY OF APPLIED SCIENCES (HSWT) AND SOIL-INSTITUTE JOHANNES PRÜGL,
ENGINEERING OFFICE FOR SOIL AND VEGETATION TECHNOLOGY

Multifunctional Infiltration Swales in Residential Areas

Rapid urbanization is leading to high levels of densification in cities and new developments. The resulting increasing soil-sealing and reduction of inner-city green spaces inevitably leads to changes in the local water balance, intensification of effects such as the urban heat-island and a decline in biodiversity in residential areas. Globally observed climate changes, including more frequent extreme events such as heavy rainfall and periods of drought, intensify the negative effects of a lack of open spaces in cities. An important element in counteracting these effects can be green infiltration swales in residential areas. In this research project, this type of near-natural stormwater-management is to be extended by the aspect of multifunctionality.

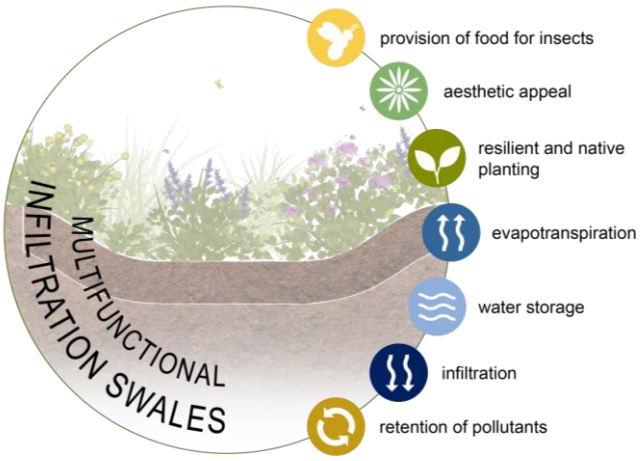

Figure 6. Functions of a "multifunctional infiltration swale"

The aim was not only the development of an improved infiltration system, but also an optimized plant- and animal-habitat (Figure 6). The research on adapted and suitable vegetation was carried out by employees of the HSWT. The Chair of Urban Water Systems Engineering (SWW) focused on the development of a engineered soil layer with substrate amendments for enhanced urban stormwater treatment. In addition to laboratory experiments on the retention of pollutants in different substrates, semi-technical experiments were set up at the SWW in 2021 to investigate the pollutant load and operational stability. This experiments at the SWW focuses on drainage safety and the retention of heavy metals and biocides from traffic-area-, facade- and roof-surface-runoff. In April 2022, piloting of a multifunctional swale in Munich was implemented with the proven soil-substrate mixtures and different plants from the semi-technical experiments. Additional, stormwater tree pits in pilot scale with the same topsoil-substrate mixtures were set up in Pfaffenhofen a. d. Ilm.

The research project was successfully completed in September 2023. The project report and a guideline are to be published in 2024. With the developed guide "Multifunctional infiltration swales - recommendations for construction and operation" for planners and municipalities, the results of the project will be transferred directly into practice.

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BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

COLLABORATION:
INSTITUTE OF ENERGY AND SUSTAINABLE DESIGN AND BUILDING (TUM),

INSTITUTE FOR REAL ESTATE ECONOMICS (IIÖ)

Accompanying research "Climate-friendly construction – model projects"

Creating affordable living spaces is challenging for developers, such as public or private investors. Adapting buildings to changing climate conditions is seen as an additional burden that further reduces the economic viability of construction projects.

The research project, a sub-project of the Centre for Urban Ecology and Climate Adaptation (ZSK) at TUM, provided scientific support for implementing ten model projects in Bavaria regarding urban climate adaptation and mitigation in residential construction. As part of the project, we evaluated climate protection and adaptation measures using a cost-benefit analysis. Side effects, such as health and environmental costs, were included in the assessment.

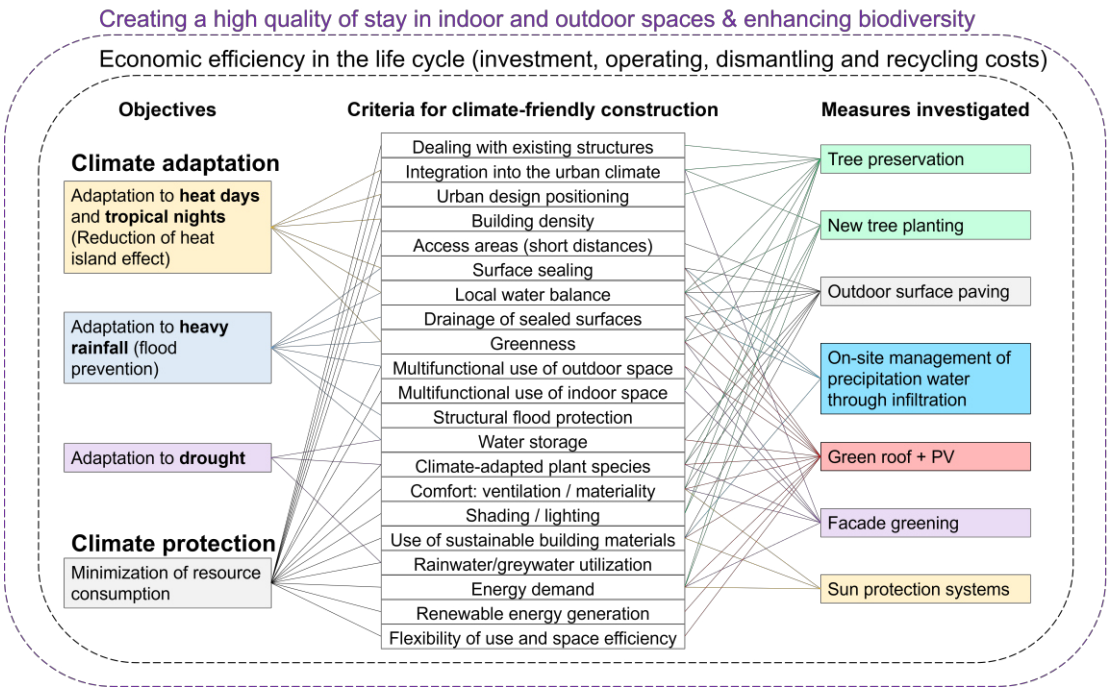

Figure 7. Objectives, criteria, and investigated measures for climate-friendly construction

By analyzing real model projects in subsidized housing construction, it was possible to show that the measures examined not only make an essential contribution to protecting against the effects of climate change but also make economic and social sense. We investigated this using the measures of tree preservation and replanting, outdoor ground coverings, infiltration systems, roof and facade greening, and sun protection.

Recognizing that long-term economic and social benefits can be achieved through increased investment costs is crucial. The early consideration of climate-friendly measures in the planning process creates the conditions for this to succeed.

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FEDERAL MINISTRY OF ECONOMIC AFFAIRS AND CLIMATE ACTION (BMWK)

COLLABORATION:
OPTIGRÜN INTERNATIONAL AG; PAUL BAUDER GMBH & CO. KG

Leaching of Mecoprop from 0° green roofs: How do extended water retention times and green roof materials influence the leaching of Mecoprop from bitumen sheets?

Urbanization, with the increasing density of cities and an increasing number of impermeable surfaces, exacerbates the negative effects of climate change. In some regions, the urban heat island effect is being promoted, and the volume of urban rainfall runoff is increasing. Low Impact Urban Design and Development (LIUDD) in the form of green roofs mitigate these negative influences (Fletcher et al. 2015). They reduce roof temperatures through evapotranspiration and increase the retention capacity of rainwater. Furthermore, the slower runoff of rainwater leads to lower peak runoff (Shafique et al. 2018). Research in recent years has focused on the choice of plants, green roof substrates, and structural differences to strengthen the mitigating effects. As an example, the 0° green roof increases the water holding capacity and water availability for plants during long droughts. Unfortunately, there has been little research on possible pollutant-leaching from new materials or the influence of longer retention times on 0° green roofs (Chenani et al. 2015). Especially the chemical root barrier layer which is used on most green roofs to prevent structural damage is treated with herbicides like Mecoprop. Even small amounts of these chemicals have a severe effect on aquatic ecosystems. Therefore, the leaching mechanism influencing factors should be investigated.

Leaching experiments in semi-technical scale are used to characterize the influence of enhanced retention times in combination with different roof structures. The experiment consists of 2 groups of root barriers and 3 types of roofs (Figure 8).

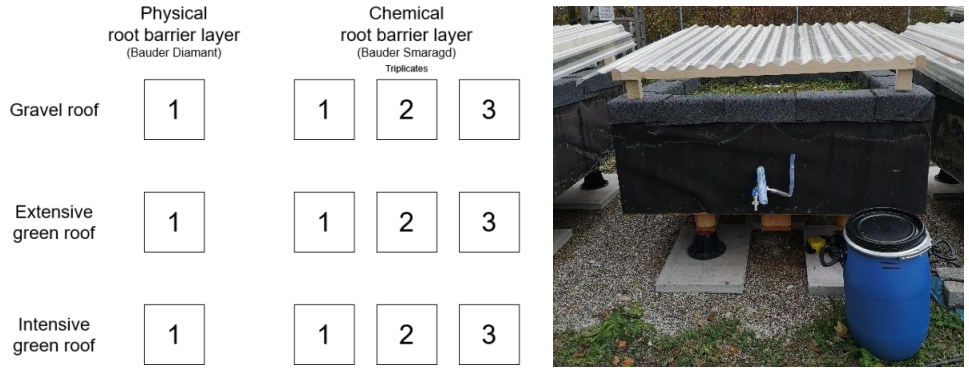
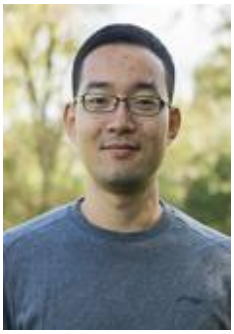


Figure 8. Experimental setup of semi-technical scale leaching experiments. Left: Different combinations of root barriers (physical, chemical) and roof types (gravel, extensive- and intensive green roof), Right: Intensive semi-technical green roof for experiments

For each experimental run the roofs are irrigated with 30 L of synthetic rainwater, which slowly seeps through the different roof structures till it reaches the root barrier layer. The water is then retained for a prolonged period with each experimental run. Further sample analysis includes the quantification of different herbicides with a combination of high-pressure liquid chromatography in combination with tandem mass spectrometry.



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CHINA SCHOLARSHIP COUNCIL (CSC)

Quantifying the binding of different biocides and heavy metals to dissolved organic matter DOM

In urban areas, during rain events, pollutants in building surfaces like heavy metals (Cu/Zn) and biocides appear in the rainwater due to the flushing and leaching processes and spreading around in the environment. Unfortunately, no high-efficiency on-site treatment facility can be used to mitigate the risks posed to the ecosystem. Therefore, we carried out some studies to understand the interactions between heavy metals/biocides with DOM and provide knowledge in treatment system design.

In a previous study, heavy metals and biocides were proven to interact with the DOM. But that is a qualitative result. The dialysis equilibrium method is used in the study to describe the interactions. Before starting the dialysis equilibrium, the used DOM was fractionated into different parts by centrifuge according to their molecular weight as DOM is a complicated mixture, various molecular weights mean different structures and binding abilities to pollutants.

Quantification of the binding of pollutants with fractionated DOM was carried out individually. Samples inside and outside the dialysis bag were collected. Heavy metals were analyzed by AAS after acid digestion removal of the DOM. For biocides, they were analyzed by HPLC-MS. The influence of Cu on biocides binding with DOM was evaluated as well.

With these studies, pollutants binding with fractionated DOM are investigated and compared.

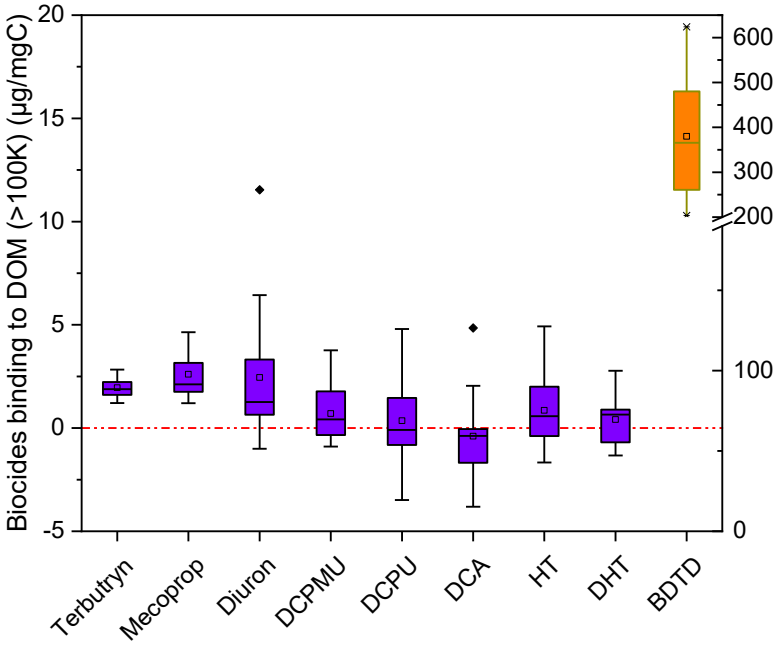

Figure 9. The amount of biocides/transformation products binding to the fractionated DOM (>100K), right Y axis is for BDTD

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GERMAN RESEARCH FOUNDATION (DFG)

Implementing biochar in bioswales for stormwater treatment

Urban stormwater is a significant pollutant source that impairs the quality of water bodies and can affect human health and ecosystems. As climate change will increase the frequency and intensity of extreme heavy rainfall and flooding, mitigating pollution from urban runoff is crucial for urban sustainability and climate change adaptation. Implementing green infrastructure –such as bioswales– for urban stormwater management is a meaningful strategy for addressing this challenge, as it can provide various ecosystem services. However, although conventional bioswales can effectively remove sediments and particulate-bound pollutants, they can fail to remove dissolved pollutants in a reliable manner.

This project aims to improve the dissolved pollutant removal in bioswales by studying the implementation of biochar, a carbonaceous material produced from the pyrolysis of organic matter. Biochar is easily available, has relatively low production costs, and can potentially remove a wide set of contaminants. The main goal is to achieve a better understanding of the possible improvements in dissolved pollutant removal and long-term retention in biochar-amended bioswales, focusing on biocides and heavy metals. The effect of changing runoff conditions (e.g., varying rain intensities and dry periods, Natural Organic Matter concentration, pH, and presence of deicing salts) will also be studied. Biochar will be studied in isolation and in combination with compost and skeletal subsoil to explore their potential for circular resource use. The effect of biochar amendments in the drainage security and in the lifespan of bioswales will also be assessed.

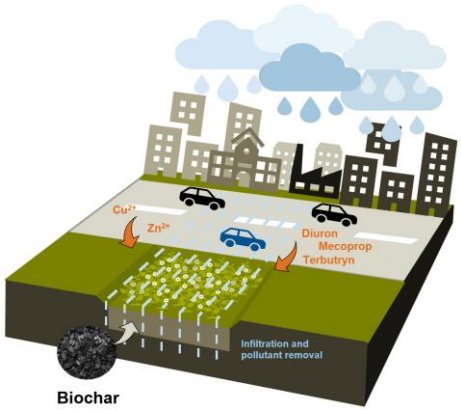

Figure 10. Conceptual framework of implementing biochar in bioswales

Preliminary results from laboratory-scale adsorption experiments with synthetic stormwater show that high-temperature (850°C) biochar from mixed forest residues has a comparable dissolved removal to granular activated carbon (GAC) (~>50% for copper and zinc; > 95% for diuron and terbutryn). Future experiments include column experiments and a mesocosm experiment for assessing the effects of the amendments in plant communities. This research is part of the interdisciplinary Research Training Group in Urban Green Infrastructure at the Technical University of Munich.

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FUNDING:
CITY OF MUNICH,
MUNICIPAL
DEPARTMENT

COLLABORATION:
UNIVERSITY OF
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BODENINSTITUT
JOHANNES PRÜGL

Pilot Project Former Bayern Barracks: Development of Soils and Substrates Recycled from Secondary Raw Materials and Evaluation Regarding Water Storage Capacity, Pollutant Retention and Plant Compatibility

In the course of the site clearance at the former Bayern barracks the city of Munich plans to recycle approx. 200,000 tons of excavated soil and processed demolition waste as plant substrates in landscaping. To minimize disposal and transport costs, as well as disposal related externalized costs such as urban traffic load and CO_2 emissions, the city of Munich plans to utilize these materials on the spot.

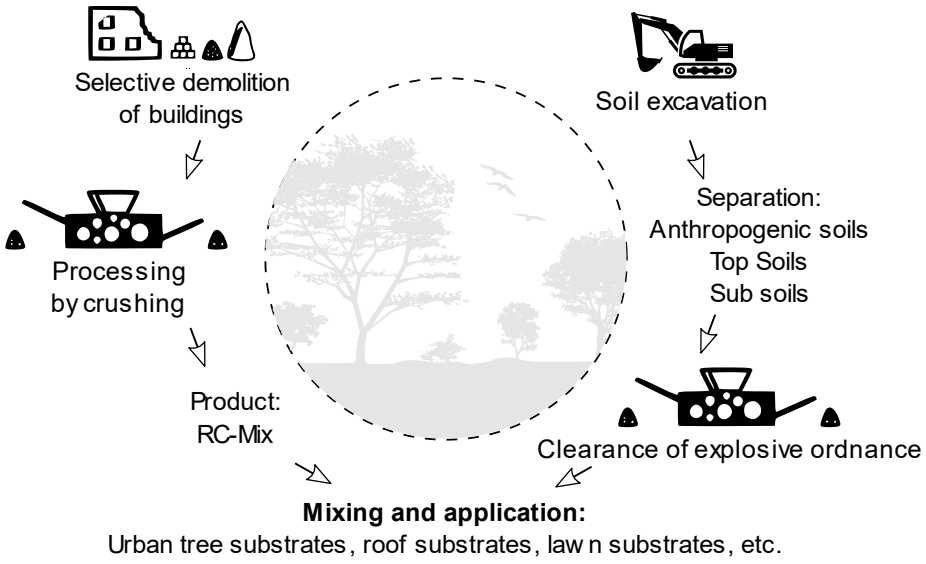

Figure 11. Process flow of secondary raw material extraction at the former Bayernkaserne Munich.

The pilot test aims to examine whether, as part of the large-scale "Bayern Barracks Munich" project, from which the new Neufreimann urban district will be created, on-site materials from building dismantling and soil excavation in urban and private green spaces can be used as vegetation-bearing and root-penetrable soil layers in the garden, and landscaping can be recycled without causing any harmful changes to the soil. In a field test, the vegetation technology and environmental and water management characteristics of tree pit substrates, which were produced on-site from different proportions of soil and RC mix of various grades, are to be examined. The experimental design was adapted to the individual planning and environmental legal concerns of BV Bayernkaserne. Still, the concept should be able to be transferred to similar LH Munich projects in the medium term in the spirit of a sustainable circular economy.

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Research Group Energy Efficient Wastewater Treatment

Wastewater treatment plants are currently still the largest consumers of municipal electricity, although there is actually more than enough energy in the wastewater than is required for its treatment. While the treatment of wastewater, taking into account the specified discharge limits, continues to be the top priority, the working group is looking for approaches to reduce the energy required for treatment on the one hand and recovering more energy from wastewater on the other hand, for example by generating biogas from the sewage sludge.

In 2023, both Carolina Feickert Fenske and Michele Ponzelli successfully defended their dissertations; congratulations! Both are now facing new challenges in the private sector, but will benefit significantly from the scientific and administrative knowledge and skills acquired during their doctorate. We wish them both all the best for their future careers.

I am very pleased that the Bavarian State Ministry of Economic Affairs, Regional Development and Energy (StMWi) has finally approved the follow-up project to the DemoMeth project that Carolina worked on. As part of the project "Microbiological methanation - Transition to commercial application" (KomMeth), which will start at the beginning of 2024 and last a total of three years, we want to work with various companies from the practice to bring biological methanation into commercial application. To this end, a wide range of tests are planned both on a laboratory scale at our chair and at the pilot plant installed at the Garching wastewater treatment plant. An important change to the previous project is the planned installation of an electrolyzer at the pilot-plant. This will bring us even closer to practical application and allow us to gain experience in the interaction between the electrolyser and the methanation system. We also want to investigate possible synergies with regard to the co-products process heat and oxygen at the wastewater treatment plant.

In addition, we are planning further tests on the membrane-based separation of metabolically produced water from the trickling liquid. Initial preliminary tests on a laboratory scale provided promising results that this should be possible with a combination of nanofiltration and reverse osmosis. Of course, the extent to which this is also economically feasible still needs to be investigated.

In spring 2024, Sergi Vinardell from the Universitat Politècnica de Catalunya in Barcelona will visit us for several months to analyze the techno-economical framework conditions of biological methanation for the two locations, Germany and Spain.

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FACHAGENTUR NACHWACHSENDE ROHSTOFFE E. V.

COLLABORATION:
HEIDELBERG UNIVERSITY, BAVARIAN STATE RESEARCH CENTER FOR AGRICULTURE

ENCOVER: Energetic Utilization of CO_2 to Enhance the Methane Productivity and to Reduce the Residual Methane Potential

The most significant source of greenhouse gas emissions is the combustion of fossil fuels. In order to achieve the goal of greenhouse gas neutrality by 2050, energy supply in the future must increasingly be based on renewable energies. Biogas production has a key role to play here, since unlike most other forms of renewable energy, it can be stored. Unfortunately, a not inconsiderable proportion of the methane potential remains in the fermentation residue when renewable raw and residual materials are fermented. Studies have shown that an enrichment of the anaerobic degradation process with CO_2 can contribute to an increase in methane productivity under certain conditions, while at the same time increasing the resilience of the process.

The goal of the project is the energetic utilization of CO_2 to reduce the residual methane potential. In the process of biogas production, renewable raw materials and especially residual materials are used, whose behavior with CO_2 enrichment in anaerobic degradation has not yet been investigated. However, their use appears to be particularly promising, since in contrast to the substrate sewage sludge, which has been investigated in particular so far, a stimulation by a significantly better substrate conversion is considered to be probable.

Within the scope of the investigations, the CO_2 uptake potential and the additional CH_4 production are to be quantified. The process stability is evaluated on the basis of pH value, redox potential and wet chemical parameters. Isotope analyses and microbiological investigations help to break down and better understand the mechanisms and processes involved. The investigations are carried out using both batch tests and continuously operated reactors on a pilot plant scale.

Beet molasses pellets, a by-product of sugar production, are currently used as a substrate. During CO_2 enrichment, one reactor is always gassed, while the second serves as a reference under otherwise identical conditions for control purposes. The reactors are gassed semi-continuously. From the knowledge gained about the process control of CO_2 enrichment of agricultural residues, it is finally necessary to derive and present recommendations for the use of the effect in practice in quantitative terms with regard to the CO_2 balance and economic efficiency.

Figure 12. Continuously operated reactors on a pilot plant scale.

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FUNDING:
GERMAN ACADEMIC EXCHANGE SERVICE

COLLABORATION:
TUM SEED CENTER

Rural Biogas Generation

By 2030, the world population will reach 8.6 billion, increasing the energy demand by 30%. This population growth will also amplify global organic waste production. To tackle these challenges, anaerobic digestion (AD) offers an innovative and resilient solution, treating organic waste while producing renewable energy in the form of energy-rich biogas and digestate, a high-value-added bio-fertilizer.

In one of our projects, we investigated the current gap in optimizing the physiochemical features of biochar (BC) and its subsequent impact on AD performance (Figure 1). The critical point of this review is to realize how the pyrolysis temperature (PyT) alone can be a crucial factor for preparing BC suitable for the enhancement of AD while neglecting other factors, such as biomass origin and activation of BC. The critical evaluation of this study includes (i) distinguishing and discussing the physiochemical properties of BC that enhance AD, (ii) establishing a correlation between PyT and the development of physiochemical features of BC, and (iii) a systematic review of AD studies to identify a potential correlation between PyT and enhancement of biochemical aspects of AD. This study will further provide in-depth knowledge and insight for researchers who deal with the application of BC for the enhancement of AD.

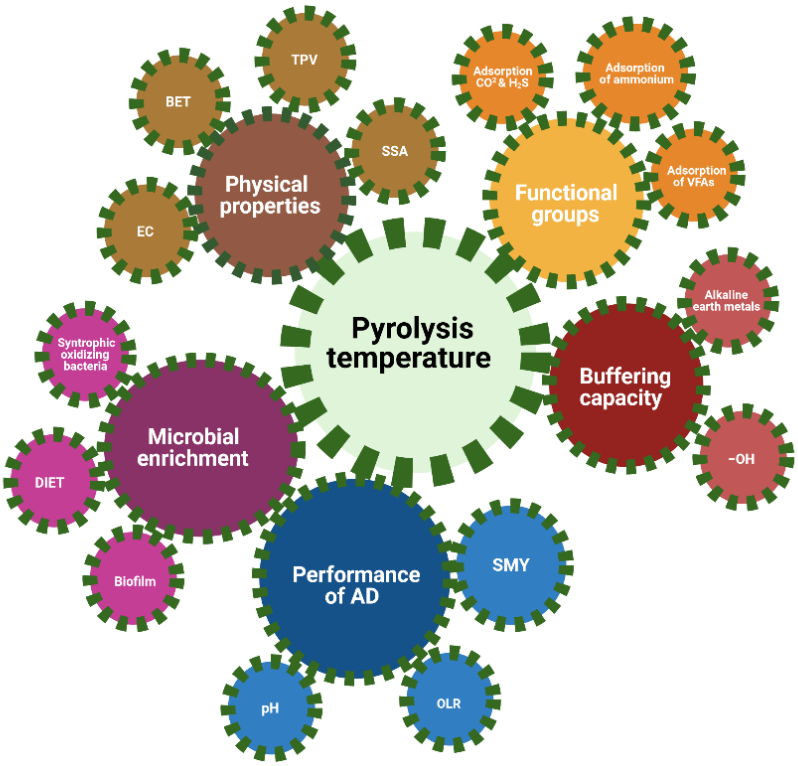

Figure 13. Effect of PyT on the performance of AD

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FUNDING:
BAVARIAN MINISTRY OF ECONOMIC AFFAIRS REGIONAL DEVELOPMENT AND ENERGY

COLLABORATION:
BAVARIAN STATE RESEARCH CENTER FOR AGRICULTURE

Optimization of the Microbiological Methanation in an Anaerobic Thermophilic Trickle Bed Reactor and Demonstration of the Reactor Performance at Pilot-Scale

Renewable energies will become the most important energy source for the energy transition in Germany. Developing conversion and storage technologies is crucial in ensuring a sustainable energy supply. An approach for flexible and demand-oriented energy storage is the generation of methane (CH_4) from hydrogen (H_2) and carbon dioxide (CO_2) (power-to-methane). In this process, H_2 is produced from unused renewable electricity by means of electrolysis, and CO_2 from wastewater treatment plants, biogas plants, or industry can be used directly at the point of generation.

The conversion of H_2 and CO_2 to CH_4 under anaerobic conditions by methanogenic microorganisms is known as a sub-process from biogas plants or digesters at wastewater treatment plants. A particularly efficient reactor concept is the gas-filled trickle bed reactor, in which the microorganisms are immobilized on carrier materials.

Thermophilic anaerobic trickle bed reactors at lab-scale already demonstrated a high performance with a CH_4 production of 15.4 $m^3_{CH4}/(m^3_{reaction\ volume}\cdot d)$ at CH_4 concentrations in the product gas above 95 %. This would allow direct injection of the biomethane into the natural gas network without the need for further gas purification. With an active reaction volume of 0.8 m^3, the applicability of the reactor concept was demonstrated on a semi-industrial scale. This makes the pilot reactor at the wastewater treatment plant Garching one of the largest anaerobic trickle bed reactors in the world. Biogas upgrading at the point of origin has a holistic potential as all resources required for the operation of the reactor can be found locally. After inoculating the reactor with digested sludge, the reactor was operated with raw biogas as CO_2 source from the local digester for a total of 450 days (Figure 14). With a stable CH_4 production of 6 $m^3_{CH4}/(m^3_{reaction\ volume}\cdot d)$ at gas grid injection quality, which corresponds to a product gas flow of 17 $m^3_{CH4}/(m^3_{reaction\ volume}\cdot d)$, taking the inert CH_4 content in the biogas into account, the potential of the energy conversion technology was demonstrated.

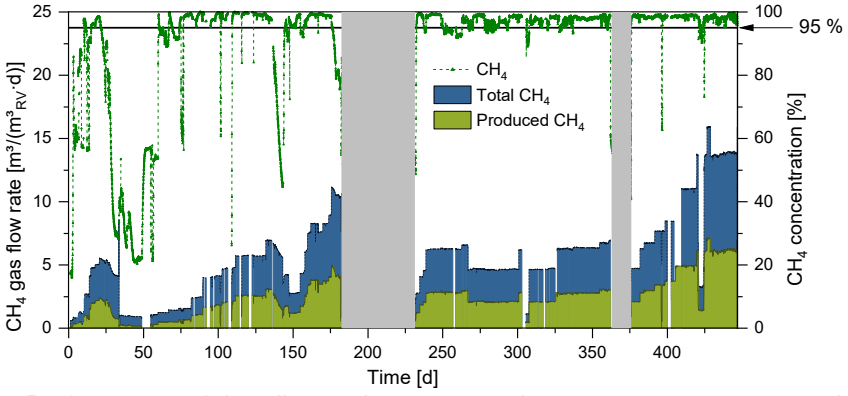

Figure 14. Performance of the pilot-scale reactor at the wastewater treatment plant Garching.

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FACHAGENTUR NACHWACHSENDE ROHSTOFFE E.V. (FNR)

COLLABORATION:
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Modelling the Degradation Kinetics of Substrates Rich in Lignocellulose for a Flexible Biogas Process in Practical Application

n 2022, the share of energy crops (e.g. maize silage) in the biomass used in agricultural biogas plants in Germany amounted to approx. 45%. Agricultural by-products (e.g. straw) and residual materials (e.g. liquid manure and dung) were used to the extent of around 49% and 3% respectively. Both substrate groups are not in conflict with food production and are characterized by a high mass potential, which is currently only partially used. Due to their composition, these substrates can only be converted into biogas comparatively slowly in the usual single-phase CSTRs.

In order to increase the use of these substrates in biogas plants, it is necessary to improve the fermentability and reliably estimate the biogas production. To this end, the project will i) investigate the pre-treatment of substrates, ii) simulate biogas production using a first-order model with one substrate fraction and iii) analyze the substitution of maize silage by by-products and residues.

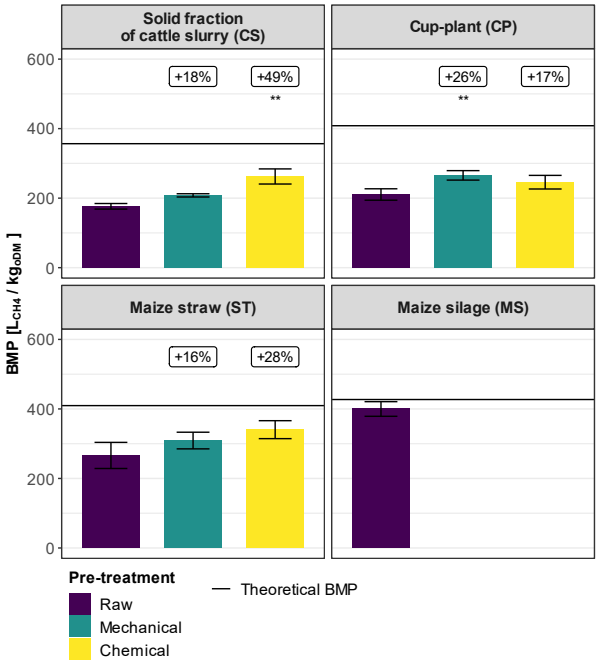

Figure 15. Effect of substrate pre-treatment on the BMP

Pre-treatment processes lead to a clear, sometimes significant improvement in the methane potential (BMP) of residues or by-products compared to the raw material. In addition, the degradation rate can also be increased (results not shown). Despite these promising results, the competitiveness of alternative substrates compared to maize silage essentially depends on the achievable revenues for the electricity generated from the biogas. At the spot market electricity prices observed in 2022, taking into account the legal framework conditions (minimum hydraulic retention time of 150 days), only maize straw represented an economically interesting alternative to maize silage: maize silage could be replaced for 25% of the time hours, taking into account the costs for harvest and storage. Despite significantly lower procurement costs, all other substrates investigated resulted in poorer profitability due to a lower biogas yield and therefore lower revenues.

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COLLABORATION:
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High-efficiency mainstream partial nitritation-anammox (PN/A): One-stage or two-stage?

Partial nitritation-anammox (PN/A) process is known as an energy-efficient technology for wastewater nitrogen removal, which possesses a great potential to bring wastewater treatment plants close to energy neutrality with reduced carbon footprint. To achieve this goal, various PN/A processes implemented in a single reactor configuration (one-stage system) or two separately dedicated reactors configurations (two-stage system) were explored over the past decades. Nevertheless, large-scale implementation of these PN/A processes for low-strength municipal wastewater treatment has a long way to go owing to the low efficiency and effectiveness in nitrogen removal.

In this work, we provided a comprehensive analysis of one-stage and two-stage PN/A processes with a focus on evaluating their engineering application potential towards mainstream implementation. The difficulty for nitrite-oxidizing bacteria (NOB) out-selection was revealed as the critical operational challenge to achieve the desired effluent quality. Additionally, the operational strategies of low oxygen commonly adopted in one-stage systems for NOB suppression and facilitating anammox bacteria growth results in a low nitrogen removal rate (NRR). Introducing denitrification into anammox system was found to be necessary to improve the nitrogen removal efficiency (NRE) by reducing the produced nitrate with in-situ utilizing the organics from wastewater itself. However, this may lead to part of organics oxidized with additional oxygen consumed in one-stage system, further compromising the NRR. By applying a relatively high dissolved oxygen in PN reactor with residual ammonium control, and followed by a granules-based anammox reactor feeding with a small portion of raw municipal wastewater, it appeared that two-stage system could achieve a good effluent quality as well as a high NRR.

In contrast to the widely studied one-stage system, this work provided a unique perspective that more effort should be devoted to developing a two-stage PN/A process to evaluate its application potential of high efficiency and economic benefits towards mainstream implementation.

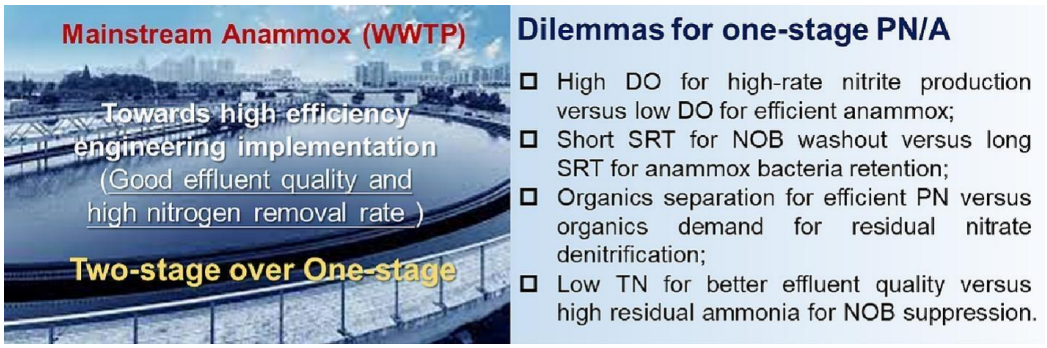

Figure 16. Dilemmas of the one-stage Partial nitritation-anammox (PN/A) process.

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Research Group Advanced Water Treatment

The research group deals with the question how to manage the anthropogenic water cycle and material cycles to supply water in sufficient quality and quantity for a growing world population in view of an accelerating climate change and attributed challenges. In the research projects we develop approaches that reflect closed water cycles contrasting the traditionally linear “take-make-waste” paradigm of centralized water supply and waste water discharge. Hence, advanced water treatment may be employed on either side, wastewater treatment or drinking water purification. This paradigm change is also propelled by current regulative initiatives, e.g. revision of EU Urban Wastewater Treatment Directive and EU regulation for agricultural water reuse. For advanced water treatment, combined or hybrid treatment processes are of paramount importance to remove:

- trace organic chemicals at ng/L to µg/L level (e.g. pharmaceuticals, personal care products, industrial chemicals),
- pathogenic microorganisms (bacteria, viruses, protozoa),
- antibiotic resistant bacteria and resistance genes, and
- nutrients at low concentration (N, P).

Hybrid treatment processes relying on different physical, chemical and biological removal mechanisms offer the multiple barriers also against contaminants of emerging concern (CEC), e.g. persistent, mobile and toxic (PMT) substances or PFAS, and even unknown contaminants. In particular, we investigate hybrid treatment processes that combine separation and conversion, e.g. adsorption – biotransformation or membrane filtration – advanced oxidation or adsorption – advanced oxidation, or that combine different separation principles, e.g. activated carbon adsorption – ultrafiltration. An important aspect of the working group is also the transfer of research results from laboratory scale to pilot- and full-scale implementation. Regarding adsorption, two objectives are pursued:

- Improve the removal performance and process efficiency by adsorbent selection (e.g. activated carbons, zeolites, metal-organic frameworks), adsorber design and operation, and adsorbent regeneration/reactivation including in-situ and on-site regeneration
- Understand and model the transport and removal mechanisms of contaminants in complex water matrices leading to competitive adsorption

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FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

COLLABORATION:
TEL AVIV UNIVERSITY (ISRAEL)

In-situ Chemical Oxidation (ISCO) by Passive Dissolution of Ozone Gas using Gas-Permeable Membranes for Remediation of Petroleum-Contaminated Groundwater

Within this joint German-Israeli research cooperation, we aim to develop membrane-based ozonation for in-situ groundwater remediation. The diffusion-driven, bubble free gas exchange via membrane contactors is a promising technology for overcoming problems of conventional groundwater remediation approaches. It could potentially lead to a more homogeneous dissolved gas distribution and a more energy-efficient process. From the combination of ozone with catalytic material as advanced oxidation process we expect an effective removal of monocyclic, aromatic compounds (BTEX) from polluted groundwater.

Fundamental research on passive, bubble-free gas introduction at low flow velocities is first conducted in lab-scale reactors (Figure 2). The test of different membrane materials shall provide more insights into options and limitations of the proposed technology. Different metal oxide materials will be used to enhance the formation of highly reactive hydroxyl radicals. This is aiming for the sufficient removal of ozone-resistant groundwater contaminants.

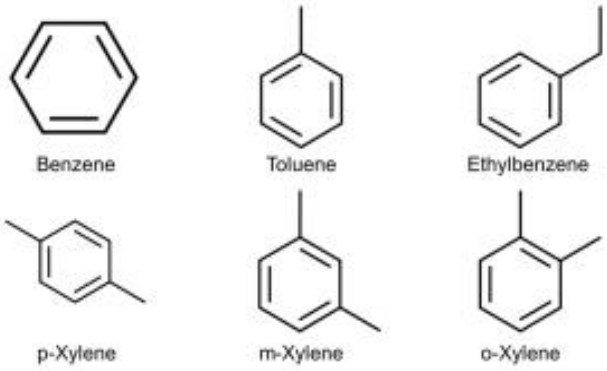

Figure 17. BTEX compounds.

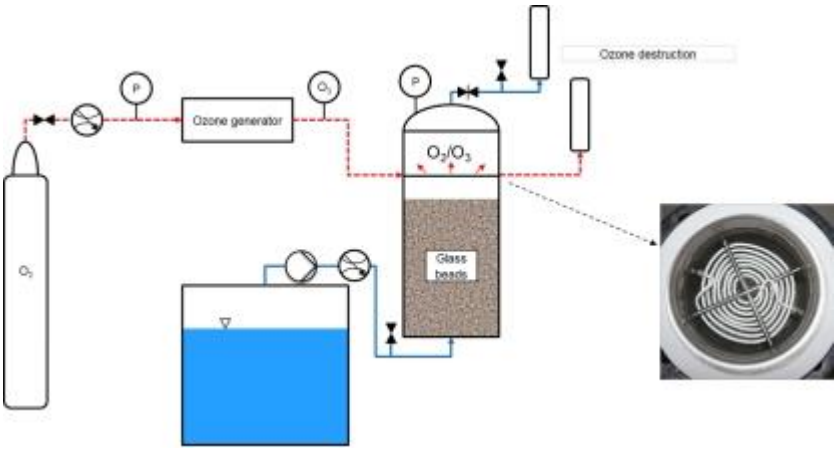

Figure 18. Experimental set-up to study in situ ozonation.

In further studies, we focus on the transformation of BTEX in ozone-based treatment and subsequent biodegradation of the transformation products.

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GERMAN RESEARCH FOUNDATION (DFG)

COLLABORATION:
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Functional Group Specific Reactivity, Transformation and Persistence of Contaminants of Emerging Concern (CECs) and their Transformation Products During Wastewater Ozonation

Chemical oxidation by ozone is an established technology for the efficient oxidation of contaminants of emerging concern (CECs) in water treatment. Its major disadvantage is the formation of ozonation products (OPs) that might have unknown and potentially detrimental effects in the environment and on human health. Currently, it is impossible to investigate each individual CEC, its reactivity towards ozone, its OPs and their biological stability and toxicity. Therefore, the generation of knowledge based on the systematic study of functional groups within CECs is a key factor to be able to understand the mechanism of reaction with ozone and its use. This information will allow the prediction of the interaction of ozone-CECs, which will improve our understanding of the formation and behavior of OPs.

The project aims are to i) generate transferable knowledge on the reaction pathways of chemicals containing specific functional groups by the treatment with ozone, ii) predict the formation of ozonation products (OPs) according to the chemical structure of the studied CECs, and iii) characterize the environmental behavior of OPs (i.e., persistence, and biological activity) depending on their chemical functionality.

To achieve our aims, we propose the use of heavy oxygen isotope (^{18}O) to produce a heavy ozone molecule, which can react with CECs and label their OPs. This labeling method will facilitate the detection, identification, and elucidation of the generated OPs through mass spectrometry.

To date, the labeling method was established with a modified ozonation system optimized for its operation with heavy oxygen ($^{18}O_2$). Furthermore, the validity of the labeling method was confirmed with an indicator compound (venlafaxine N-oxide) for determination of the $^{18}O/^{16}O$ ratio, and applied to label OPs from seven different compounds with N-and S- containing functional groups. Therefore, it is possible to identify OPs formed by oxygen transfer reaction, highlighting their reaction site and functional group availability of the parent compound. Finally, the concept is now applied to track and assess the stability of labeled OPs in biological treatment systems.

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COMISSION

COLLABORATION:
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UNIVERSIDADE DE
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COMPOSTELA

(SPAIN)

Development of novel materials and systems for the removal of per- and polyfluoroalkyl substances (PFAS) from water

As a part of the Marie Curie International Training Network NOWELTIES, this project aims to develop methods and process optimizations for removing per- and polyfluoroalkyl substances (PFAS) from municipal and industrial wastewater. Based on a critical literature assessment, two promising treatment concepts have been identified, which w

ill be investigated in this study.

Together with the Friedrich-Schiller-University in Jena, we intend to further explore proven concepts of degradation through ultrasound cavitation and to establish the potential for optimization of these processes through a set of carefully designed experiments. The advantages of such a process are simplicity, robustness and no chemical input required. The goal is to reduce the high operational costs due to its energy demand by coupling with a pre-concentration step using nanofiltration or reverse osmosis membranes. As an end goal this project aims to design a system capable of efficiently and effectively treating industrial wastewater prior to release into recipient water systems.

In close collaboration with the Chair of Inorganic and Metal-Organic Chemistry, TU Munich we are also developing and testing the performance of metal-organic framework (MOF) materials primed to elicit extraordinary adsorption capability towards PFAS present in trace amounts in water sources. This is done through:

1. structural modifications of the materials both by changing the structural properties of the material surface (different functional groups, different properties and performance expected) and through introducing structural defects
2. Post-synthesis modification and composite material fabrication in order to maximize the potential of used materials

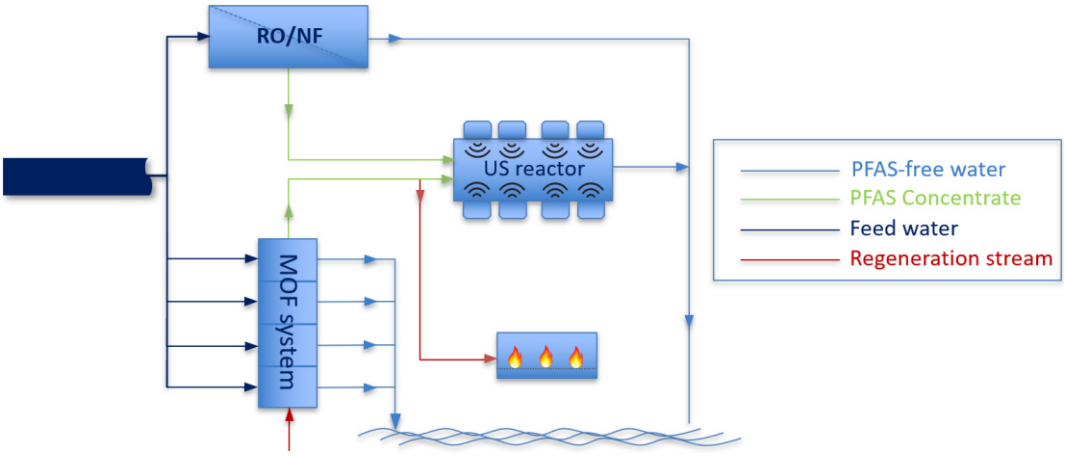

Figure 19. Schematic representation of the treatment concept for PFAS-polluted water.

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EUROPEAN COMMISSION

COLLABORATION:
THE CATALAN INSTITUTE FOR WATER RESEARCH (SPAIN)

Elucidation of Metabolic Strategies for the Degradation of Trace Organic Chemicals Under Oligotrophic and Oxic Conditions

NOWELTIES is a Horizon 2020 Marie Sklodowska-Curie Innovative Training Network composed of 14 individual research projects. The common objective for all projects is to develop innovative water treatment technologies. Within this project, we aim to elucidate pathways in the metabolism of TOrCs.

We developed a retentostat system (Figure) to study the bacterial metabolism of TOrCs under stable oxic and oligotrophic conditions. Aniline, histidine, and di-sodium succinate were selected as the unique carbon source to adapt bacteria from activated sludge.

Figure 20. Current experimental setup able to run 10 experiments in parallel.

In 7 days of exposure experiments, most substances showed similar behavior among all the microbial communities (Figure). No effects were observed for recalcitrant compounds, such as carbamazepine, either for substances reported as removed, such as metoprolol or gabapentin. Sulfamethoxazole and atenolol were transformed by all microbial communities.

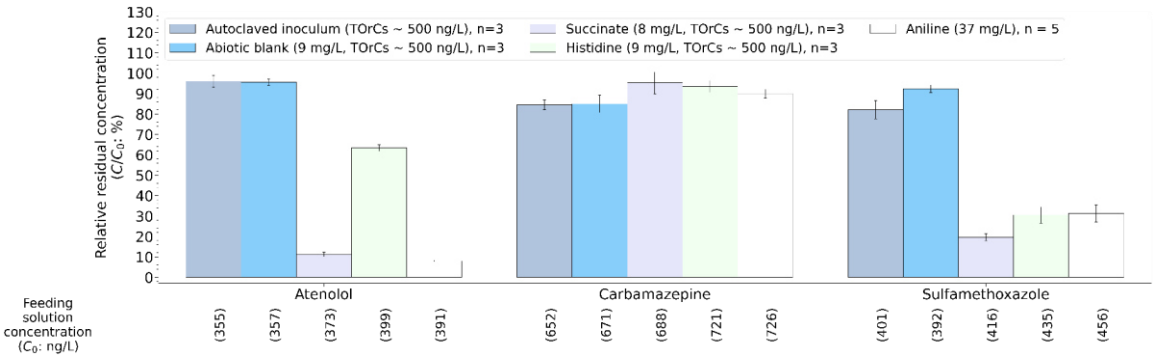

Figure 21. Relative residual concentration (C/C_0) of selected TOrCs after treatment with different microbial communities, and abiotic blanks.

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FUNDING:
BAVARIAN ENVIRONMENTAL PROTECTION OFFICE

Elimination of Trace Organic Compounds (TOrCs) at Small-Scale Wastewater Treatment Plants: Using the Example of the Irschenberg Treatment Plant (<10.000 p.e.)

Anthropogenic trace organic chemicals (TOrCs) enter the aquatic environment through conventional wastewater treatment plants (WWTP) where they pose a significant environmental challenge. In Germany, elimination of TOrCs will be mandatory for large WWTPs and for those with small, sensitive receiving water bodies after the amendment of the EU Urban Wastewater Treatment Directive. Solutions for TOrC removal specifically designed for small WWTPs are still lacking because the state-of-the-art of activated carbon (powder or granular) and ozonation are not suitable (maintenance and operation constraints) or economic (economy of scale) under these conditions. However, small WWTPs represent the largest share of overall number of WWTPs in Germany and Europe alike. In this research project, the WWTP Irschenberg (5,000 p.e.) was selected as a case study. A vertical flow constructed wetland (VFCW) with integrated activated carbon is designed for TOrCs elimination and partial hygienisation as an advanced treatment step and implemented as an effective low-cost and low-maintenance treatment strategy. Our research aims to evaluate the performance of pilot-scale column experiments that simulate VFCWs. Our two objectives are 1.) Understanding the interplay of hydraulics, ad-/desorption, biodegradation including co-metabolism and process conditions (Redox, O_2, pH, nutrients, BDOC/BOD) and 2.) Identifying design and operational criteria for the large-scale VFCW in Irschenberg. The results of this study will contribute to the development of sustainable and cost-effective solutions for the many small WWTPs to protect sensitive receiving waters and ensure the overall health of aquatic ecosystems.

COLLABORATION:

IB DR. SCHREFF; DAK/ENWACON ENGINEERS

The first phase of the research project runs from October 2022 to October 2024.

Figure 22. Experimental set-up

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FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COLLABORATION:
CENTRE FOR BUILDING MATERIALS AND MATERIAL TESTING (CBM)

Research on treatment mechanisms of cementitious materials in the treatment of wastewater from the textile industry

Textile wastewater, complex due to dyes, electrolytes, softeners and dispersants, represents a challenge for wastewater treatment. Azo dyes in combination with dyeing salts, which are difficult to remove using conventional methods, are particularly problematic. These are often too energy-intensive and costly, especially for low-income regions where textile factories are predominantly located, such as in South Asia and India. Low-cost treatment methods, such as adsorption processes, are therefore essential for wastewater treatment.

Adsorbents made of cement paste containing granulated blast furnace slag with different grain sizes were developed, which can adsorb various dyes. The study focussed on both the cement paste and its individual phases, particularly those with a layered structure. The surface charge, which changes with the pH value of the wastewater, significantly influences the affinity of the negatively charged dye for adsorption. This relationship can be illustrated using the zeta potential in Figure 1. The monocarboaluminate shown adsorbs seven times more dye at pH 5 than at pH 11. In addition, the decolourisation capacity of the cement paste was analysed taking into account the pH value and the presence of various salts such as MgSO4, NaCl or NaSO4.

Furthermore, the reusability of the granulates was analysed in the context of the circular economy. Thermal treatment at approx. 300 °C enabled the hyratised cement paste to be reused with 99% of its original decolouring capacity.
The research project is being carried out jointly with the Centre for Building Materials and Materials Testing (cbm) at the Technical University of Munich.

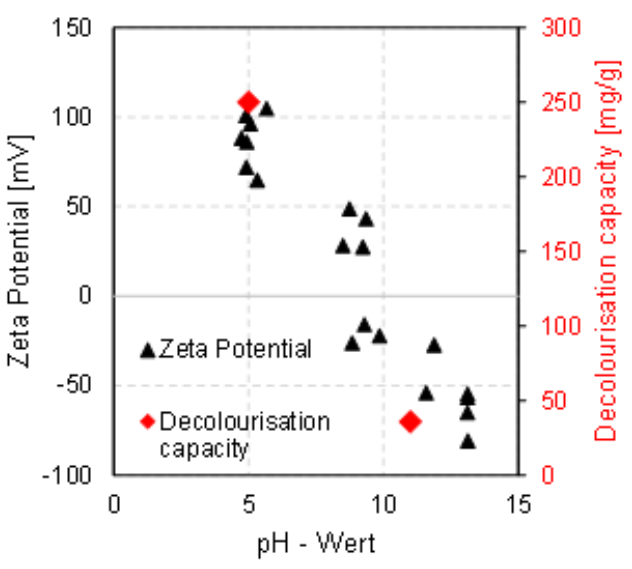

Figure 23. Zeta potential and decolourisation capacity of monocarboaluminate

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Research Group Water Reclamation and Reuse

According to an estimate by the World Resources Institute, a quarter of the world's population lives in regions with acute and extreme water scarcity. The situation is expected to worsen worldwide in the coming decades. In particular, rapid population growth, increasing urbanization, advancing industrialization and agricultural activities, exacerbated by the effects of climate change, are putting enormous strain on our global water resources.

Water reclamation and reuse can efficiently and sustainably overcome water resource problems by creating new sources of high-quality local water supply, partially replacing already scarce freshwater resources. In particular, stormwater and the reuse of (municipal) reclaimed water and its reuse can effectively mitigate the challenges associated with increasing water use conflicts. In May 2020, the EU published for the first time a new regulation on minimum requirements for water reuse for agricultural irrigation. This legislation must be implemented by the EU member states into national law by June 2023. Due to this development, but especially due to the noticeable consequences of climate change, there is now also a great need for action for water reuse in Germany. Building on a feasibility study in Lower Franconia, we started the new joint project 'Reclaimed Water' in 2021 funded by the Federal Ministry of Education and Research (BMBF), which develops concepts for safe water reuse for urban and agricultural irrigation on a demonstration scale. In addition, water reuse can also serve to augment groundwater supplies. Also funded by the BMBF, we launched the new project TrinkWave Transfer' in close collaboration with the Berlin Water Works to investigate alternative concepts at a former water works site in Berlin.

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Nutzwasser: Reclaimed water as alternative water resource for urban and agricultural irrigation

The area around Schweinfurt is a region with traditionally pronounced water scarcity, in which water use conflicts are increasingly occurring due to the effects of climate change. Therefore, the so-called "Nutzwasserprojekt" was initiated in this region. The aim of the "Nutzwasserprojekt" is to develop practical management strategies for water reuse for urban and agricultural irrigation and to optimize them within the framework of relevant demonstrations with industry partners in such a way that implementation in other target regions is accelerated.

The 3-year research project is divided into different work packages:

- Elaboration of the prerequisites for a **legal implementation** for the application of reclaimed water
- Establishing **water quality requirements** for different irrigation practices
- Development of digital approaches for the automated determination and of the **irrigation demand**
- Implementation of **innovative multi-barrier treatment technologies** for the efficient removal of microbiological and chemical contaminants
- Development of an automated, **needs-based provision of reclaimed water**
- Conception of **adapted operator models**
- Embedding the project in an interactive **stakeholder process** and
- Establishment of an innovative **public relations platform**

Link to the project website: https://www.nutzwasser.org/public/index.html

FUNDING:

FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COLLABORATION:

BAYERISCHE LANDESANSTALT FÜR WEINBAU UND GARTENBAU, WASSERWIRTSCHAFT DER REGIERUNG VON UNTERFRANKEN, DEUTSCHER VEREIN DES GAS- UND WASSERFACHES E.V., XYLEM WATER SOLUTIONS DEUTSCHLAND GMBH, STADTENTWÄSSERUNG SCHWEINFURT

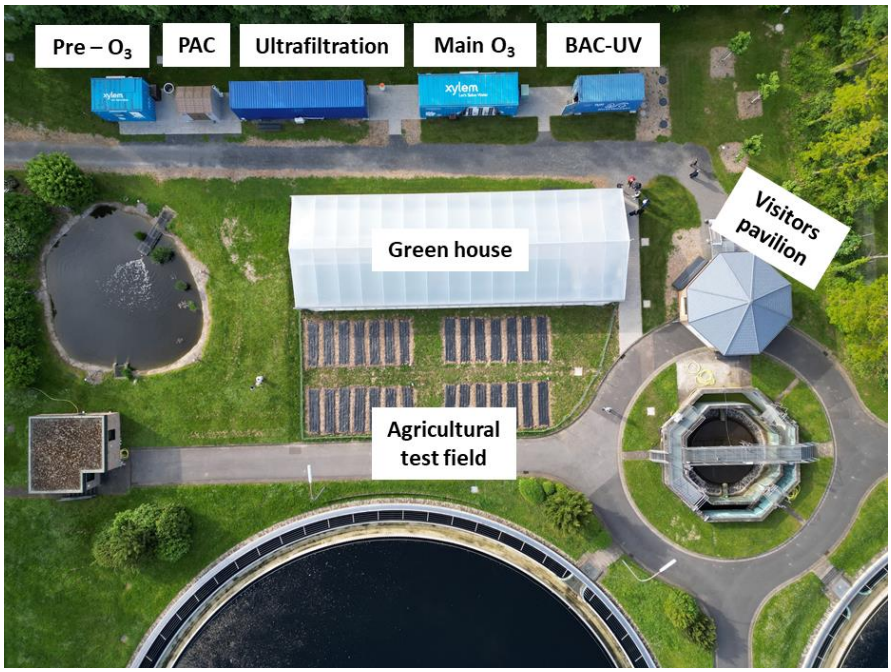

Figure 24. Aerial view of the demonstration systems on the premises of the Schweinfurt municipal drainage system

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FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

COLLABORATION:
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Development and Optimization of an Innovative Treatment Approach for Indirect Potable Reuse in Urban Water Cycles

During the TrinkWave joint project, which was completed and funded by the BMBF (Federal Ministry of Research and Education), new multi-barrier treatment processes for water reuse based on sequential managed aquifer recharge technology (SMART) were developed. The aim was to assess multidisciplinary monitoring approaches for innovative process combinations of water reuse to support the drinking water supply.

The subsequent joint project TrinkWave Transfer (funded by the BMBF), is now testing the large-scale implementation of the SMART process in collaboration with the Berliner Wasserbetriebe, the University of Oldenburg and BGS Umwelt GmbH. This is taking place at the former Berlin-Johannisthal waterworks site, where the process will be demonstrated in its optimized form with integrated high-infiltration trench technology and active hydrological control in the subsurface. The knowledge gained from the previous project and from the SMARTplus technical pilot system will be incorporated into the planning and implementation.

In addition to the scientific support of the field study in Berlin, the investigation and further development of the SMARTplus system takes place at the TUM in Garching. With the SMARTplus pilot plant at the TUM, it is possible to analyze the efficiency of the reduction (biotransformation) of anthropogenic trace substances at the pilot scale. Aiming for further characterization and optimization as well as improved hydraulic conditions, the integration of further barriers for the establishment of a multi-barrier system will be investigated. The focus is also to enhance an adequate process monitoring system at the pilot-scale plant at the TUM.

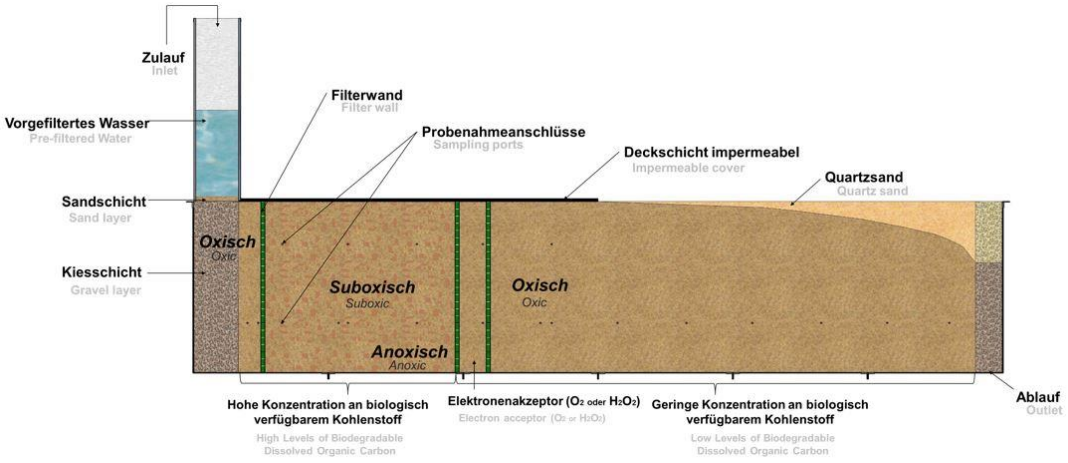

Figure 25. Schematic of the SMARTplus pilot-scale test facility at TUM (adapted from Karakurt-Fischer et al., 2020).

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Research Group Urban Water-Energy-Food (WEF) Nexus

With ongoing economic growth, urbanization and industrialization, demand for natural resources such as water, energy and food continue to rise worldwide, especially in cities. The result is serious environmental challenges and climate change. Integrated urban planning to leverage on potential synergies of climate change mitigation and adaptation approaches and measures urgently needs to be developed and implemented by 2030 to avoid disastrous climatic change.

The Water-Energy-Food (WEF) Nexus approach is one integrated urban planning way for cities to devise more sustainable development pathways. The approach advocates that supplying water to cities takes much energy, and that much water is also needed to produce energy and food. Planning these three sectors in an integrated manner can support water, energy and food security and achievement of the United Nations Sustainable Development Goals (SDGs). Water reclamation with integrated resource recovery is a key synergy opportunity for the operationalization of the WEF Nexus approach.

Figure 26. WEF NEXUS approach.

However, so far, few examples exist where this has been implemented at urban scales. More case study development and pilot projects are urgently needed in order to test the viability of this approach. Further, such development needs to be embedded from the outset in a participatory multi-stakeholder process.

Within the TUM Nexus Lab initiative (Nexus@TUM) founded by Dr. Gondhalekar in 2021, the Urban WEF Nexus Research Group uses the Nexus approach as an integrated urban planning framework to analyze the interactions between the sectors water, energy and food, as well as other related sectors such as mobility, solid waste, health and ecosystem services, and devises alternative future urban development scenarios to support the development of pilot projects at urban scales. Nexus@TUM aims to build on an environmental engineering perspective by integrating all three pillars of sustainability and connecting these to social, institutional, legal, political, and economic aspects, in an equal manner. Nexus@TUM further acknowledges that the issue at hand pertains equally to contexts in developing as in developed economies. The research group works in several case study locations including Germany, Ghana, India, Niger, South Africa and Tunisia.

Figure 27. Series of international Urban WEF Nexus workshops.

For more information, please visit www.nexus.wasser.tum.de

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WEF Nexus Pilot Project in Reto Dosso, Niger: Sustainable Water Supply with Analysis of Water Reclamation and Integrated Resource Recovery Potential as Part of a Climate Adaptation Strategy

Figure 28. Dar es Salaam, Reto Dosso region, Niger.

This project is part of a larger cooperation project funded by the German Federal Ministry for Education and Research (BMBF, 2020-2024) titled “Science meets school – renewable energy powered water-food-economy Nexus for improvement of living conditions in the Dosso Region in Niger”. The aim of the Nexus Group project part is, to initiate a Nexus dialogue, build and strengthen academic networks on the topic, and to develop and implement a Nexus pilot project as part of a climate change adaptation strategy with sustainable water supply (drinking as well as other uses) coupled with an analysis of the potentials of water reclamation and integrated resource recovery as a key Nexus opportunity. This study is undertaken using a typical case study, a secondary school campus in a village in the Dosso Region of Niger. Using geographic information systems (GIS) the project will develop and visualize alternative development scenarios with suitable technology options as a basis for a participatory multi-stakeholder discussion in order to secure from the project outset the co-creation process of the pilot project together with the local community, thereby enabling co-ownership. In parallel, the project aims to conduct capacity building to anchor sustainable use of water as part of a climate change adaptation approach in the region.

By supplying drinking water and water for various other uses in a ‘fit-for-purpose’ sustainably, e.g. for agricultural irrigation or aquifer recharge, the project aims to create a revenue stream at a model scale that in turn aims to enable a public-private-people organized operation. The potential of resource recovery through biogas and organic fertilizer generation is also analysed. The hypothesis is that such an innovative framework can be the foundation of an innovative decision-making and socio-economic governance model, that can contribute to more sustainable development of cities under climate change impacts as well as to achieve the UN SDGS, especially SDG6 Water und SDG2 Food Security. Further, the project aims to gain insights into the key enabling factors for operationalizing the Nexus approach and in particular water reclamation with resource recovery through the implementation of the pilot project, thereby generating results transferable to other regions. The pilot project is being developed and implemented as a lighthouse project for climate change adaptation, and will generate results with very high relevance for the built environment and cities in the region and worldwide. Press release: https://www.th-koeln.de/hochschule/solaranlage-fuer-die-lokale-wirtschaft_76314.php

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SEED-Himalaya: Sustainable Energies, Entrepreneurship and Development in rural Kashmir

FUNDING:
FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND CLIMATE ACTION (BMBK)

This project is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK, 2022-2025) under the International Climate Initiative (IKI) Programme.

The livelihood of the rural population in Jammu and Kashmir is particularly threatened by climate change due to the negative impact of varied rainfall patterns and more frequent extreme weather events on local agriculture in combination with unreliable energy supply. This leads to economic stress, poverty, and limited employment opportunities, in particular for the youth.

SEED Himalaya aims to support the remote Himalayan community of Jabri in its transformation into an environmentally resilient and economically empowered community. This is to be achieved through community-based, decentralized energy supply as well as local value creation in agriculture. The inclusive bottom-up development plan, covering both green infrastructure as well as socio-economic structures, is tailored to the local resources, capacities, and needs. This ensures the sustainability of the project and enables the replication of its approach in other Himalayan communities.

Now that all 140 households have been equipped with PV modules and battery storage for basic power supply, the local value chain for agricultural products and the advanced mini-grid required for this, including a do-it-yourself water wheel, are being planned in collaboration with our Indian project partners and community members.

COLLABORATION:
ASEEM FOUNDATION (INDIA),
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY (IITB, INDIA)

Figure 29. The project community Jabri in the Indian state of Jammu and Kashmir.

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FUNDING:
BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION (STMUV)

COLLABORATION:
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UNIVERSITY OF CAPE TOWN (UCT, SOUTH AFRICA)

Water-Hub project in Western-Cape Province, South Africa

This pre-feasibility study will apply an integrated Water-Energy-Food (WEF) Nexus approach to examine appropriate nature-based technologies that can expand the scope of the current activities to recover reclaimed water and other resources in the context of informal settlements, at the research site "The Water Hub" in Franschhoek, Western Cape (Figure 30).

Figure 30. Pollution of local water bodies due to inadequate wastewater management in local informal settlements.

This project will contribute to the improvement in water, energy and food security in the Western Cape Province while protecting the environment and regenerating ecosystem services, hence helping to achieve the UN SDGs. As such the project's Nexus approach will take WEF as the starting point, but explicitly includes other relevant sectors such as waste and ecosystem services as a basis for a just transition to a circular economy. TUM will be collaborating with three other project partners in the execution of the study, namely, the Bavarian State Ministry of the Environment and Consumer Protection (StMUV) in Germany, as well as the Western Cape Government, Department of Environmental Affairs and Development Planning (DEA & DP) and the University of Cape Town in South Africa (UCT).

The main objectives of the prefeasibility study are to assess opportunities for resource recovery at the Water-Hub. This includes the examination of water quality and the effectiveness of currently implemented nature-based treatment methods and the implementation of further solutions such as sequential managed aquifer recharge technology (SMART). Further, the project will examine the feasibility of water reclamation and reuse, assess energy recovery through anaerobic co-digestion of different feed stocks, support development of business plans for entrepreneurship opportunities from organic (food) waste-to-energy streams, nutrient recovery (organic fertilizer) etc., and serving local markets. Additionally, benefits for ecosystem services regeneration by deploying this Nexus approach will be assessed and knowledge dissemination and capacity building among project partners and stakeholders will be fostered due to the enabling environment provided by the Living Lab concept of the Water Hub.

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COLLABORATION:
IESP.INTERNATIONAL EXPERT GROUP ON EARTH SYSTEM PRESERVATION E.V.

Nexus Convergence Project in Tunisia

The relationship between the ability of afforestation and deforestation to respectively increase or decrease the amount of precipitation and evapotranspiration and its effect on the water balance and ecosystem of a region is particularly important to the resilience of vulnerable groups to the challenges of climate change. In regions of the world with increasing forest tree cover loss coupled with water scarcity such as Tunisia, alternative water sources such as treated municipal wastewater reuse can play a crucial role in supporting afforestation/reforestation projects that can have positive effects on the regional water balance and ecosystem hence improving climate resilience.

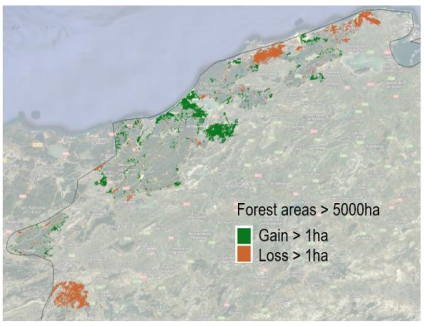

Figure 31. Remote sensing analysis displaying forest tree cover gain and loss in North-Western Tunisia

This StMUV funded project aims to characterize the scientific, geographic-climatic (climate change), technical as well as socio-economic basis in Tunisia to carry out a partnership-based reforestation to influence the water balance of the region in a sustainable way. The reforested area should be able to achieve the following long-term goals:

- Serve as a carbon sink to capture CO_2 and regulate the local climate.
- Generate additional precipitation by reactivation of the *biotic pump* and thus provide enough water for the forest and the surrounding area.
- Contribute to the socio-economic development of the local population.
- Serve to a limited extent as a communal area for the local population for preservation and protection.
- Provide evidence of the positive influence of reforestation on soil characteristics (e.g. moisture content). This can provide valuable knowledge for the Bavarian Ministry for the replication of reforestation projects in Bavaria.

The preservation of the forest must be of clear economic benefit to the population for sustainable project implementation. The project therefore aims to facilitate acceptance for the long-term project sustainability through involvement of all stakeholders from the project outset. The lessons learned from this project will add to the existing knowledge on relationship between loss of forest tree cover (deforestation) and increasing water scarcity.

Figure 32. Visible loss of forest cover in the Jendouba Governorate in North-Western Tunisia

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Research Group Membrane Filtration

Membrane processes play a central role while establishing closed water cycles, for the reuse of municipal wastewater as well as in seawater desalination. The research of the Membrane Filtration group at the chair currently focuses on the suppression of biofouling by integrating UV-LEDs into membrane modules, the combination of powdered activated carbon and ozone with ceramic ultrafiltration membranes, the retention of microbial and chemical contaminants in high-pressure membranes, as well as fouling mitigation strategies by alternative membrane surface patterns.

Since the end of 2018, we have been working in a BMBF project on the question of how far unwanted biofouling on the membrane, which affects the energetic efficiency of the membrane process, can be reduced. By using UV-C LEDs, we are developing UV-membrane hybrid processes in which targeted UV pre-treatment delays the formation of biofouling and, at the same time, UV-induced effects in microorganisms to positively influence the properties of the formed biofilm in terms of its permeability and cleanability.

The coupling of powdered activated carbon with ultrafiltration membranes results in high efficiencies for the retention of microbial contaminants but also organic trace substances. In this context, the mechanisms of retention of antibiotic resistance carriers need to be clarified in more detail in order to ensure high effluent quality. Furthermore, the formation of cover layers has to be optimized in such a way that operational advantages result. These water qualities would allow reuse for urban and agricultural irrigation as well as artificial groundwater recharge.

In 2022, we have launched the new project FreeSpace in collaboration with the University of Duisburg-Essen funded by the German Research Foundation (DFG) to investigate membrane fouling mitigation strategies by employing modified membrane surface patterns and new spacer configurations.

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FUNDING:
GERMAN RESEARCH FOUNDATION DFG

COLLABORATION:
UNIVERSITY OF DUISBURG-ESSEN: CHAIR OF MECHANICAL PROCESS ENGINEERING & WATER TECHNOLOGY

Freespace: Fundamental Research to Exploit Hydrodynamic Effects to Reduce Membrane Fouling by Introducing Special Arrangements of Novel Feed Spacer Geometries in Combination with Non-Regular Membrane Surface-Pattern

In this DFG-funded research project, we investigate synergistic influences of membrane surface patterning and feed spacer geometry on fluid dynamics and particle deposition mechanisms in the feed channel. This research will promote our understanding of fundamental design criteria that determine the overall module performance. With this understanding, special arrangements of feed spacer and surface pattern geometries will be designed. This novel development concept is believed to allow for higher process efficiency, longer module lifespan, and less energy consumption.

Biofouling, the accumulation of microorganisms and subsequent biofilm growth on the membrane, is of particular concern in Nanofiltration and Reverse Osmosis systems. Therefore, in order to understand the spatial and temporal evolution of biofouling on surface-patterned membranes, we perform accelerated biofouling experiments with semi-synthetic feed water. A pre-defined protocol allows conducting biofouling experiments in a well-defined and reproducible manner.

In parallel to this experimental approach, we investigate different feed spacer and membrane pattern geometries by CFD Modeling with COMSOL Multiphysics 6.1. In these models, we investigate e.g. wall shear stresses (Figure 1) to understand the respective hydrodynamics. We hypothesize that fluid mixing (ultimately leading to lower fouling) is significantly enhanced in geometric assemblies of surface-patterned membranes (micrometer scale) and feed spacers (millimeter scale) compared to the geometry of one of those features alone.

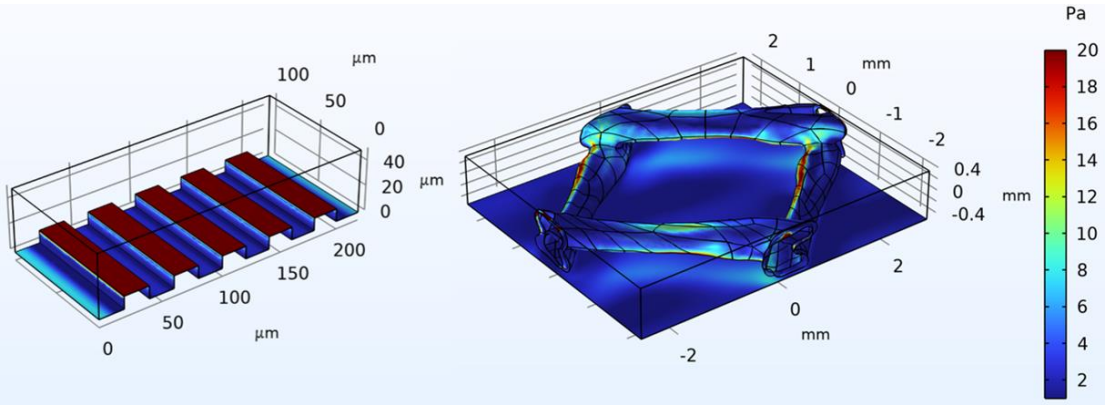

Figure 33. Shear stress distributions in surface pattern geometry on micrometer scale (left) and feed spacer geometry on millimeter scale (right).

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Research Group Microbial Systems

The Emmy-Noether Junior Research Group Microbial Systems focuses on the investigation of microbial processes in aquatic and technical systems ranging from biological wastewater treatment to surface water ecosystems. Microorganisms are tiny, yet crucial organism that cycle our planets resources and keep our biosphere balanced, and thus provide vital ecosystem services. We are interested in the microbiomes of engineered and natural water treatment. Therefore, our overall aim is to develop tools that specifically measure and qualitatively assess microbes and their functions in water systems. We perform hypothesis driven and descriptive research that allows to link microbes to ecosystem services.

Our research hereby focus on the interaction and diversity of organisms within microbial biofilms with a focus on fungi and their function. Fungi produce very efficient exoenzymes that can transform difficult-to-degrade organic substances. Of particular interest are the largely unexplored aquatic fungi and their diverse functions in the environment. Further research is concerned with the characterization of the taxonomic and functional diversity of microbial communities with specific functions, e.g. with regard to microbial degradation or antibiotic resistance genes in the water cycle. Here, we focus on diverse biomarkers. Most recently, we have examined the potential of biomarkers in wastewater by quantifying biomarkers from the SARS-CoV-2 virus. This can be used to monitor the pandemic in the population and report it back to public health officials.

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FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

COLLABORATION:
TECHNOLOGIEZENTRUM WASSER - PRÜFSTELLE WASSER (TZW DVGW)

Wastewater Biomarker CoV2: Wastewater Epidemiology Using the Example of a SARS-CoV-2 Biomarker for the Estimation of COVID-19 Infections on the Population Scale

Wastewater-based epidemiology (WBE) is gaining popularity as a diagnostic method to estimate drug and medication use for entire sewersheds. SARS-CoV-2 can also be used as a biomarker in the context of wastewater diagnostics, on the one hand to detect a change in the infection pattern at an early stage and on the other hand to better elucidate the number of unreported COVID-19 cases at the population scale. For this purpose, the amount of virus in wastewater must be reliably analyzed and detected. The detection of SARS-CoV-2 is based on different PCR analyses with previously prepared wastewater samples (see work flow in Figure 1). In this regard, there is a need for research to harmonize methods for enveloped viruses such as SARS-CoV-2, on the optimization of the treatment procedures for the detection of the amount of virus in raw wastewater, and on the active integration into the corona infection management of the health authorities.

For the correct estimates of virus concentration in the wastewater, it is also very important to consider other factors, such as population density, the size and coverage of the sewer system, the volume of wastewater generated, degree of extraneous water, and substance-specific variables such as excretion rates, as well as the fate and transport of SARS-CoV-2 in the sewer network. To reduce the uncertainty of the wastewater-based monitoring, these factors must be considered when estimating the incidence of infection. The results from this project can be used to develop a novel SARS-CoV-2 biomarker concept that will serve as an early warning system and can also be used to estimate the spread of infection directly by authorities. Such a concept may be extended to an estimation of the incidence of infection by other viruses or its early detection or tracking. Meanwhile, an ArcGIS-based dashboard has been developed for faster data sharing and better networking. This concept enables fast information management and short decision-making paths.

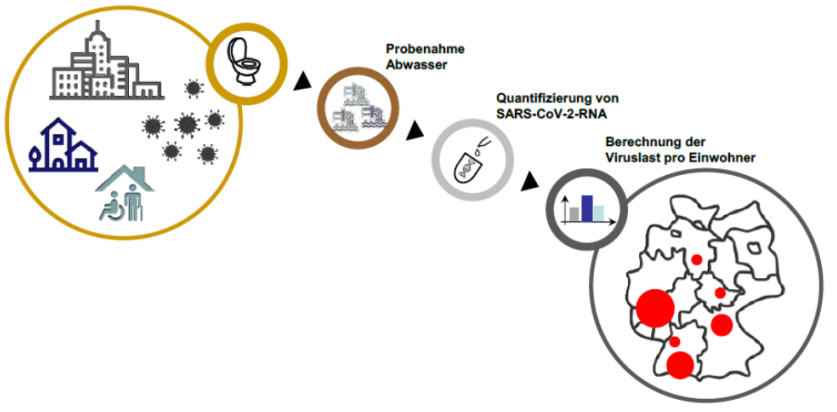

Figure 34. Concept of wastewater monitoring of SARS-CoV-2. Image: Claudia Stange, Johannes Ho. Collaboration with TZW Karlsruhe. Funded by BMBF.

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Wastewater Biomarker CoV2: Wastewater Epidemiology Using the Example of a SARS-CoV-2 Biomarker for the Estimation of COVID-19 Infections on the Population-Scale

SARS-CoV-2 biomarkers can be used as an additional metric for pandemic management in the context of wastewater-based epidemiology. This requires reliable detection of the number of biomarkers in the wastewater, which starts with studying the effects of transport in the sewer system and subsequently taking representative samples.

Diurnal variations: Due to the characteristic excretion behavior, the occurrence of SARS-CoV-2 biomarkers in wastewater is subject to diurnal fluctuations. We postulate that the succession pattern is related to the number of people served by the wastewater treatment plant and the length of the sewer system in the catchment area. We sampled seven wastewater treatment plants in southern Germany, with 8100 to 1.1 million people served over 48 hours. The samples were analyzed for SARS-CoV-2 biomarkers and other surrogate parameters (PMMoV, CrAssphage, flow, ammonium, TOC, electrical conductivity and various trace substances). First results show different daily patterns of biomarker concentrations for the different communities, with higher variance in smaller communities, as shown in Figure 1. Further analyses will be used to derive suitable sampling strategies depending on the size of the community and the length of the sewer system. A correlation analysis will be carried out with the surrogate parameters and possibilities for normalizing the biomarker results will be examined.

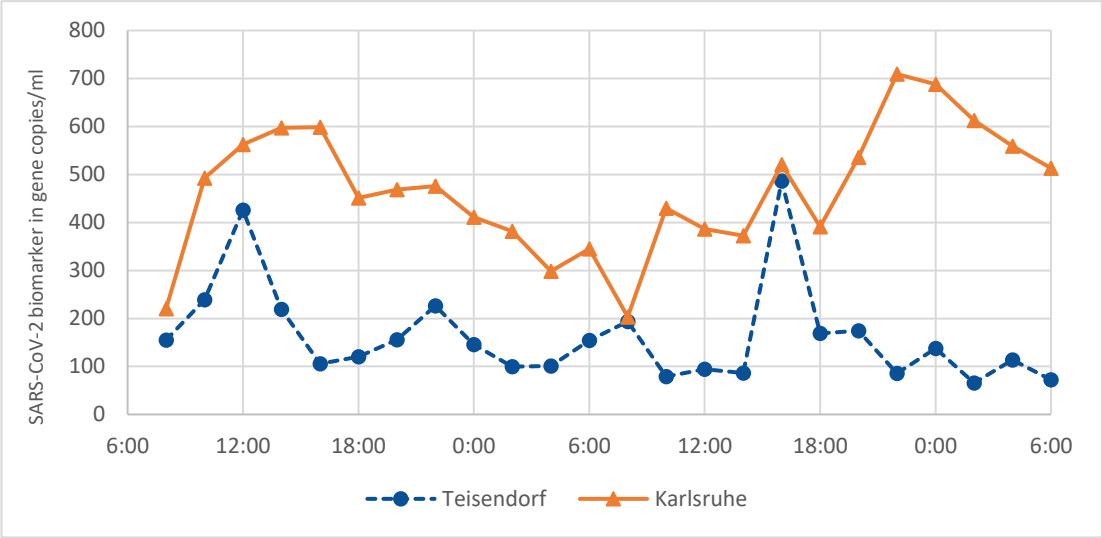
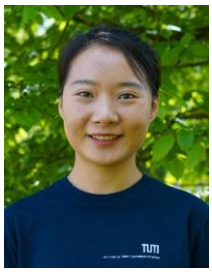


Figure 35. SARS-CoV-2 biomarker concentrations in Teisendorf and Karlsruhe over 48 hours

With the end of the coronavirus pandemic, we are now investigating the possibility of qualitatively and quantitatively measuring other relevant biomarkers in wastewater.



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FUNDING:
CHINA SCHOLARSHIP COUNCIL (CSC)

COLLABORATION:
STOCKHOLM UNIVERSITY (SWEDEN)

Establishment of microbial model communities capable of removing trace organic chemicals for biotransformation mechanisms research

Removal of trace organic chemicals (TOrCs) in aquatic environments has been intensively studied. Some members of natural microbial communities play a vital role in transforming chemical contaminants, however, complex microbial interactions impede us from gaining adequate understanding of TOrC biotransformation mechanisms. To simplify, in this study, we propose a strategy of establishing reduced-richness model communities capable of removing diverse TOrCs via pre-adaptation and dilution-to-extinction.

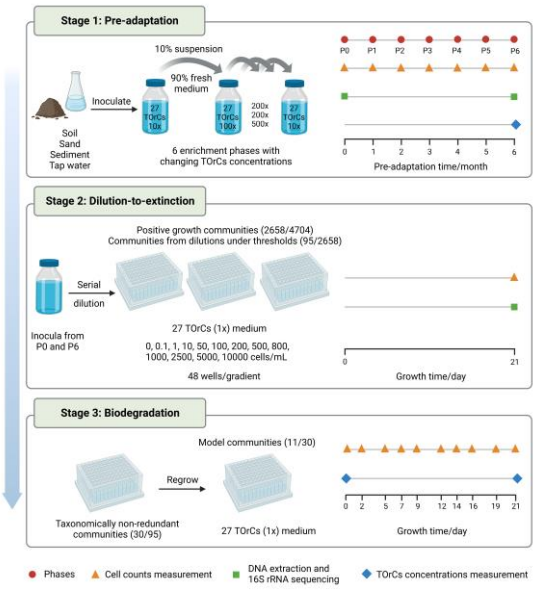

Figure 36. Workflow of model communities establishment.

Microbial communities were adapted from tap water, soil, sand, sediment deep and sediment surface to changing concentrations of 27 TOrCs mixture. After adaptation, the communities were further diluted to reduce diversity into 96 deep well plates for high-throughput cultivation. After characterizing microbial structure and TOrC removal performance, thirty taxonomically non-redundant model communities with different removal abilities were obtained. The pre-adaptation process was found to reduce the microbial richness but to increase the evenness and phylogenetic diversity of resulting model communities. Moreover, phylogenetic diversity showed a positive effect on the number of TOrCs that can be transformed simultaneously. Pre-adaptation also improved the overall TOrC removal rates, which was found to be positively correlated with the growth rates of model communities.

This is the first study that investigated a wide range of TOrC biotransformation based on different model communities derived from varying natural microbial systems. This study provides a standardized workflow of establishing model communities for different metabolic purposes with changeable inoculum and substrates. The obtained model communities can be further used to find the driving agents of TOrC biotransformation at the enzyme/gene level.

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GERMAN
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COLLABORATION:
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ALPINE AND POLAR
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RESEARCH CENTER
(ALPOLE)

Biodiversity of aquatic fungi in pristine and impacted surface waters

Freshwater ecosystems are among the most impacted on Earth, having high rates of biodiversity loss due to ongoing climate change and anthropogenic pollution such as industrial wastewater effluents and urban and agricultural runoff, among others. This current rates of species loss across many organism groups imperil the maintenance of the ecosystem services they provide, including nutrient recycling, carbon sequestration and water purification.

Microbial decomposers, particularly aquatic fungi, are known to play a vital role in ecosystem dynamics in freshwater forested streams, reliant on the energy input from allochthonous sources, such as leaf litter. This group is the main contributor to carbon and nutrient cycling, by producing and secreting extracellular enzymes that: (i) break down polymeric and recalcitrant organic matter into smaller, assimilable molecules and (ii) cycle nutrients, such as nitrogen and phosphorus. Despite this pivotal role to freshwater ecosystem functioning, the taxonomic and functional diversity of these fungi is currently poorly understood and characterized. The lack of knowledge on this group is even more striking when considering their genetic diversity, particularly their potential to remove recalcitrant compounds and pollutants, such as trace organic chemicals.

In order to help fill in these knowledge gaps, this project aims to gain insight into aquatic fungal diversity and functioning in pristine and impacted aquatic environments across distinct alpine zonations using both, classical and molecular identification methodologies. The research objectives comprise the cultivation and characterization of aquatic fungal communities in different aquatic environments, assessments of biodiversity and the degradation pathways, as well as microbial interactions during degradation processes in an entire landscape context. To enable these analyses, the development and optimization of standardized workflows for rapid isolation of fungal isolates (pure cultures), (meta-)barcoding, and metatranscriptomics of aquatic fungi are sought.

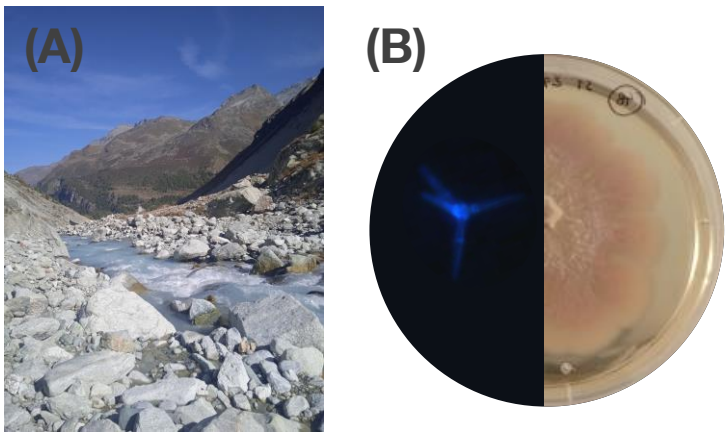

Figure 37. (A) Glacier-born alpine stream in the region of Sion, Switzerland. (B) Aquatic fungal isolation: From spore to pure cultures.

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FUNDING:
GERMAN RESEARCH FOUNDATION (DFG)

COLLABORATION:
BAVARIAN STATE RESEARCH CENTER FOR AGRICULTURE (LFL)

Aquatic fungi in biofilms of water treatment systems: Abundance, dependencies and function of Cryptomycota

Fungi are known to be dominant in terrestrial systems performing biological breakdown of organic carbon which is crucial for the carbon cycle. However, their role in the aquatic environment is largely uninvestigated. Different environmental and diversity studies show their presence in a brought spectrum of aquatic habitats and highlight the lack of knowledge of this kingdom. In the last years even a whole new phylum, the *Cryptomycota*, was discovered and proven to be present in almost every water sample taken.

Especially in engineered biological systems, it is crucial to consider the fungal kingdom during investigations to understand and optimize the work considering the whole microbial community. The superordinate objective of this research is to gain insight into and a better understanding of the fungal community in WWTPs in general with a focus on *Cryptomycota*. To enable this, existing molecular biological methods needed to be adjusted, leading to the development of a specific and reliable qPCR protocol targeting *Cryptomycota*. After this achievment, the microbial community in down-flow hanging sponge (DHS) reactors is used as a model community to get insight into the abundance and interactions of fungi and other microorganisms involved in wastewater treatment. DNA and cDNA Illumina sequencing and metatranscriptomical analyses are used to observe the function of *Cryptomycota* in those complex communities.

To this point of research, a suitable qPCR system to quantify *Cryptomycota* was successfully implemented. The reactor performance was analysed and comprehensive quantitative and qualitative c/DNA studies over reactor height and operation time are giving insight into diversity and abundance of microrganisms.

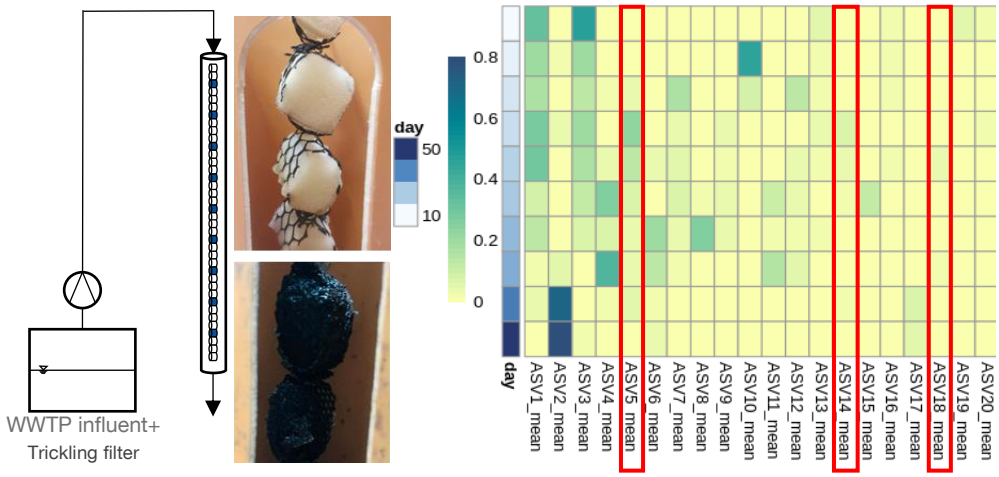

Figure 38. DHS reactor sketch, clean as well as overgrown polyurethane sponge filling material, and results of 18s cDNA abundance analysis over the growth time (red marked amplicon sequence variants (ASVs) were classified as Cryptomycota).

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DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT (GIZ)

COLLABORATION:
ROBERT KOCH INSTITUTE AND THE SANITARY-EPIDEMIOLOGICAL WELFARE AND PUBLIC HEALTH COMMITTEE OF THE REPUBLIC OF UZBEKISTAN (SANEPIDCOM)

Feasibility Study: Implementation of a wastewater surveillance system (WSS) for COVID-19 in Tashkent

Wastewater-based epidemiology has garnered interest as a monitoring tool to protect public health, especially since the pandemic. A feasibility study was initiated to detect and monitor the prevalence of COVID-19 in Tashkent, Uzbekistan was monitored through the establishment of a wastewater monitoring system (WSS). Five programmable, stationary, refrigerating autosamplers were stationed at a total of five influent points across three wastewater treatment plants.

Strategy: 24-hour composites were taken in duplicates, two times a week. Viral RNA was extracted and SARS-CoV-2 target genes *N2* and *E*, as well as surrogate virus *Pepper Mild Mottle Virus* (*PMMoV*), were quantified through quantitative PCRs. Statistical analyses were conducted to determine the differences between the technical replicates and to analyze the trend of SARS-CoV-2 in Tashkent.

Preliminary results: Comparison of the replicates with respect to *N2* and *PMMOV* showed no significant difference (p values of 0.1 and 0.29, respectively) between the duplicates and as a result, replicates were no longer sampled and extracted. A linear regression analysis was conducted between the wastewater data from each sampling site, and the 7-day incidence data from Tashkent. Almost no correlation was found between the datasets, with a maximum R-squared value of 0.022. This can be attributed due to the end of the pandemic, as well as discontinuation of mandatory testing.

Feasibility: Technologically, the equipment was compatible with local infrastructure, and the existing skillset was enough for the tasks. The system requires a large capital for setup and has recurring costs for laboratory consumables. The material and consumable costs for processing a single batch of samples (extraction and qPCR of 5 composites) is calculated to be 11.13 cents per 1,000 Tashkent inhabitants. The operation is relatively simple to maintain and troubleshoot. Redesigning or altering the pipeline (i.e. targeting a different biomarker) requires technical expertise for the planning phase.

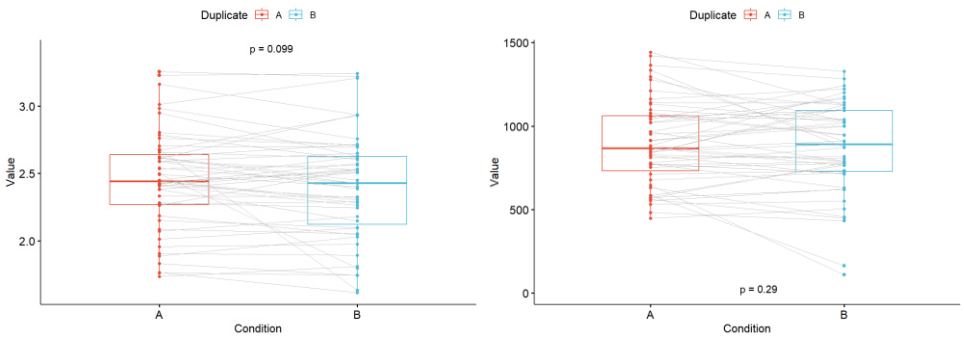

Figure 39. Boxplots of transformed data from the technical replicates, with SARS-CoV-2 gene N2 (left) and PMMoV (right) datasets analyzed

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SWEDISH RESEARCH COUNCIL (VR)

COLLABORATION:
SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES (SWEDEN, HOST INSTITUTION

The fungal contribution to the carbon cycle of Subarctic and Arctic permafrost areas

Climate change is causing the thawing of Artic permafrost, which stores twice the amount of carbon than the atmosphere. The thawing process leads to the collapse of the landscape and the formation of thaw ponds that receive this organic matter (OM) and thus are considered hotspots for the carbon cycle. Microorganisms are responsible for breaking down organic compounds, which results in greenhouse gases (GHG) emissions. A massive release of previously frozen OM could not only threat Artic ecosystems but accelerate climate change globally. Therefore, there is an urge to understand how this OM is processed by microbial communities in thaw ponds, to further evaluate the impacts of a thawing Arctic. While there is a lot of ongoing research on this topic, a group of microorganisms is largely understudied: the aquatic fungi. Despite their role as decomposers of the OM in soil, we barely know about what fungi can do in water. Here I present my postdoc project aims to study the functional potential and carbon cycling activity of aquatic fungal communities in Arctic thaw ponds. Water and sediment from the ponds will be analyzed and combined with metagenomes, fully sequenced fungal isolates, dissolved OM quality data, single cell sequencing, carbon assimilation assays (DNA/RNA stable-isotope probing) and metatranscriptomics to: a) analyze the functional potential, in terms of carbon degradation, of aquatic fungi across a thaw gradient (from pristine to degraded sites – Figure 1); and b) conduct an in-depth functional analysis of the fungal community from a Swedish permafrost site significantly impacted by thawing.

It is expected that degraded sites with more terrestrial (allochthonous) OM have higher potential for degradation of organic compounds. On the other hand, the pond water from pristine sites, which concentrates higher proportions of autochthonous dissolved OM than degraded sites, may present higher potential for cell growth. I also hypothesize that prevalent the sediment may concentrate the highest fungal activity for the degradation of carbon compounds, compared to water. This project will increase the understanding on the role of aquatic fungal communities in carbon cycling in thaw ponds, an important step to better estimate the impacts of climate change in permafrost areas.

Figure 40. Sampled sites.

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FUNDING:
GERMAN SCIENCE FOUNDATION (DFG)

EMMY NOETHER PROGRAM

COLLABORATION:
LEIBNIZ INSTITUTE OF FRESHWAER ECOLOGY AND INLAND FISHERIES (IGB)

Shedding light into fungal dark matter: Ecology and genetic potential of Rozella sp. in Fuchskuhle

Fungi are an integral part of global ecosystems through nutrient cycling and ecosystem balance and dynamics. Despite their significance, a substantial portion of fungal taxa, especially in aquatic ecosystems, remains undescribed and is referred to as dark matter fungi. Cryptomycota, a fungal group found abundant in aquatic environments, including wastewater, constitutes a large fraction of the fungal dark matter. Using cutting-edge molecular tools, this project aims to shed light on the ecology of these understudied organisms.

In this study, we focus on Cryptomycota from Lake Fuchskuhle, a shallow, acidic bog lake situated in northern Germany. This lake is part of a long-term manipulation experiment, monitored since 1986. Our collaborators at the Leibniz Institute of Freshwater Ecology confirmed the presence of Cryptomycota in Lake Fuchskuhle through metagenomic studies. Using sequential water filtration and targeted quantitative PCR, we located the highest abundance of Cryptomycota at a depth of 3 meters in the living fraction of particles measuring 0.65µm (**Figure 41A**). Subsequently, employing the recently developed laser-dissection microscopy workflow, we isolated individual Cryptomycota cells for single-cell whole-genome sequencing (**Figure 41B**). The obtained DNA sequences, along with metagenomic data, are currently undergoing bioinformatic processing. This information will be utilized for both the genetic and functional characterization of the captured organism. Our next step involves the evaluation of the abundance of Cryptomycota over seasonal variations and corresponding changes in water properties, using samples of an 8.5-year time series provided by our collaborators. This comprehensive analysis will identify environmental parameters influencing Cryptomycota abundance and their role in this unique bog lake ecosystem.

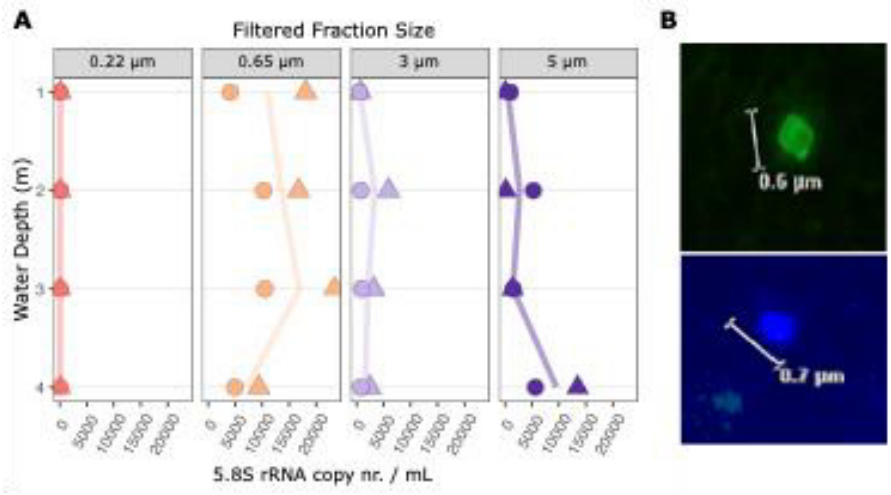

Figure 41. A) Abundance of Cryptomycota determined by quantitative PCR of the 5.8S rRNA sequence in sequentially filtered lake water of different depths. Panels represent different filter sizes, and shapes represent replicate samples obtained from water volumes of 200 and 400 mL respectively. B) Cryptomycota cell stained with the cell wall stains Wheat germ agglutinin (green, upper) and Calcofluor-white (blue, lower). µ

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Research Group
Trace Organic Compounds in the Environment

A broad range of compounds is introduced into the environment due to the modern human lifestyle, some of which show high biological activity. These organic trace compounds (TOrCs) contain classes of (crude-)oil, pesticides, and industrial chemicals, as well as household chemicals and pharmaceuticals (pain killers, antibiotics, x-ray contrast media, etc.). Though normally only traces (< µg/L) of these compounds are found in the environment, the high biological activity of the compounds could lead to harmful effects on humans and other organisms.

Hence, the focus of this research group is to develop new methods to detect TOrCs in the environment, as well as detecting the alteration of TOrCs by natural and oxidative processes. The main interest here is the evaluation of water treatment processes and the determination of the condition of the aquatic environment.

An outline of the aims of the working group:

- Broadening of the target screening for the monitoring of TOrCs in (waste-) water treatment
- Elucidate natural and oxidative degradation processes and identify the resulting degradation products
- Develop new methods to determine sorption behavior of TOrCs onto microplastic particles
- Validation of a sample preparation method for the assessment of microplastic in the environment
- Establishing a target method for perfluorinated alkyl substances (PFAS) in water treatment systems

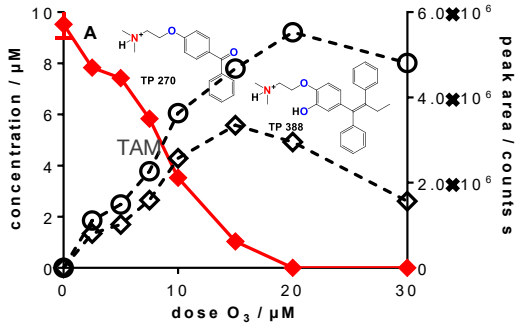

Figure 42. Left: AB Sciex QTRAP 5500 mass spectrometer for the identification of transformation products. Right: Example for the formation of transformation products during ozonation.

External Doctoral Candidates

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FUNDING: BAVARIAN ENVIRONMENT AGENCY

Investigation of PFAS contamination in the effluent of municipal wastewater treatment plants using the TOP assay

The total concentration of per- and polyfluorinated alkyl substances (PFAS) in aquatic environmental samples can be determined using the TOP assay (Total Oxidizable Precursor Assay). Thereby, polyfluorinated precursor compounds are degraded by oxidation to the analytically detectable perfluorinated carboxylic acids (PFCA). The values determined by the TOP assay can be compared with the directly determined PFCA concentrations of the target analysis in order to get information on the proportion of unknown PFAS in the total PFAS concentration.

PFAS could be detected in all investigated WWTP effluents. 21 of the 40 individual PFAS compounds investigated were detected at least once in concentrations greater than the limit of quantification. In the untreated wastewater samples, the compounds C4 - C8 PFCA were detected most frequently. In addition, the precursor compound 6:2 FTAB was detected in a large part of the wastewater treatment plants. PFPeA, PFHxA, 6:2 FTS and 6:2 FTAB were detected in the highest concentrations with values between 1.0 and 3.6 µg/L.

An increase in PFCA concentration after the TOP assay was observed for all wastewater treatment plants investigated. On average, the PFCA concentration increased by a factor of 4. The TOP assay thus provides evidence that the actual PFAS load in wastewater is higher than the PFAS target analysis due to the presence of unknown precursor compounds.

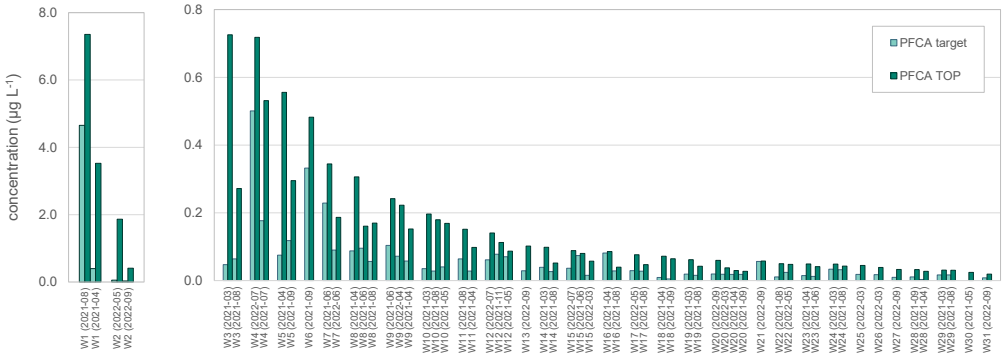

Figure 43. PFCA concentration in the effluent of the investigated WWTPs before (PFAS target) and after oxidative treatment (PFCA TOP).

Hanna Ulrich is an external PhD student and works at the Bavarian Environment Agency. Hanna's doctoral thesis is supervised at the TUM by Prof. Dr. J. Drewes and Dr. PD T. Letzel.

Visiting Scientists

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FUNDING:
ALEXANDER-VON HUMBOLDT-FOUNDATION
INSTITUTION NAME

Abatement of environmental microplastics in contaminated water using functional materials

The menace of environmental microplastics (MPs) has raised a serious global concern in recent years. Due to the emerging hazards that MPs release into environmental water, there is an imperative need to combat this quagmire, so as to make the ecosystem better habitable for human, flora, fauna and aquatic lives. An attempt to solve this problem led to the syntheses and applications of zeolite series immobilized on porous biochar templates (ZIB) for effective removal of mono-dispersed polystyrene microspheres from contaminated water.

Experimental data from this study revealed that ZIB adsorbed 0.47 to 4.90 $mg.g^{-1}$ (9.40 to 98%) of mono-dispersed polystyrene microspheres in contaminated water for agitation time of 1 to 180 min respectively (figure 1). Also, further study revealed that ZIB adsorbed 0.44 to 4.97 $mg.g^{-1}$ (8.80 to 99.4%), 0.38 to 4.94 $mg.g^{-1}$ (7.60 to 98.8%) and 0.38 to 4.91 $mg.g^{-1}$ (7.60 to 98.2%) at various temperatures of 20 ℃, 35 ℃ and 50 ℃ respectively. This trend is attributable to the rapid mobility of the mono-dispersed polystyrene microspheres into the active sites and pores of ZIB as a result of temperature rise and increase in the kinetic energy of the mono-dispersed polystyrene microspheres as they migrate to the surface of ZIB.

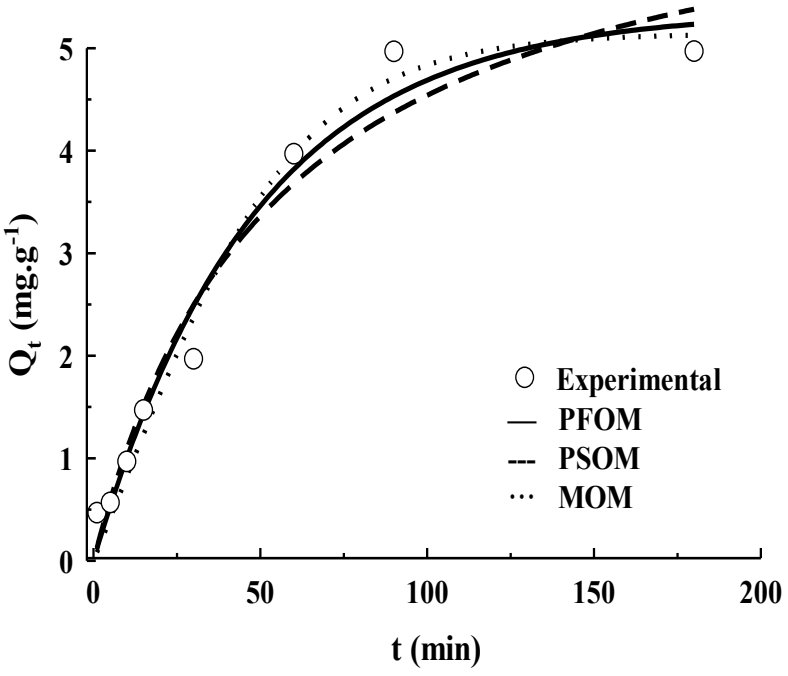

Figure 44. Plot of Q_t ($mg.g^{-1}$) against time t (min) (Adsorbent dose: 0.05 g, agitation time: 1-180 min, temperature: 20 ℃, initial concentration: 10 $mg.L^{-1}$, pH: 7.0).

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FUNDING:
PON-REACTEU ("RESAERCH AND INNOVATION" BY EUROPEAN UNION)

COLLABORATION:
UNIVERSITY "FEDERICO II" OF NAPLES, ITALY

Effect of low-frequency ultrasound process on digested sludge contaminated with trace organic compounds

Anaerobic digested sludge (ADS) is the output of anaerobic digestion (AD), one of the main strategies used for both stabilization and reduction of sewage sludge volumes. Despite the fertilizing properties of the ADS, the presence of persistent organic pollutants represents a limit to its safe use as a soil amendment.

Figure 45. Soxhlet extraction of the solid phase of ADS.

The low-frequency ultrasound (US) treatment of sewage sludge is known to promote the organic matter hydrolysis and to enhance the methane production kinetics during the AD of sewage sludge (SS). Nonetheless, the high energy inputs to operate US devices are not counterbalanced by the energy gain from the additional methane produced by US-treated SS.In the last years, US treatment has gained attention for the reduction in the concentrations of trace organic compounds (TrOCs) in sludge, but few works attempt to provide a total mass balance of TrOCs after the sludge Us treatment. The aim of this work is the assessment of the effects of the low-frequency US treatment on contaminated ADS. In this way, the non-selective US effects will be concentrated only on the bio-recalcitrant organics, likely allowing the energy input reduction. For this study, the ADS was sampled from two different wastewater treatment plants in southern Germany. A chemical extraction method based on Soxhlet was developed for the qualitative and quantitative analysis of 33 different emerging contaminants in the solid phase of the ADS, mainly pharmaceutical active compounds, and the concentrations in both the solid and liquid phase of sludge were quantified by LC-MS/MS measurement, providing information on the presence of TrOCs, and also their partition before and after treatment.

Figure 46. Bench-scale ultrasound treatment.

Increasing the soluble COD up to 330% depending on the energy input, the US treatment influenced the partitioning behavior of the TrOCS, with a change in the distribution of the pollutants in both the solid and the liquid phases. The reduction in the concentration of TrOCs in the solid phase was dependent on the initial concentrations of the contaminants as well as their own physical-chemical properties, but also on the characteristics of the sludge, and it was mainly related to the disaggregation of the flocs and to the consequent increase in the solubilization of the organic matter in the liquid phase.

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FUNDING: AALTO UNIVERSITY (FINLAND)

Lab to Water

Despite increasing efforts and commitments over the past few years, we are not on track to achieve the Sustainable Development Goals by 2030, especially for some developing countries in Asia and Africa, they are leaving behind in nearly all SDGs. Regional inequality is unavoidable problem when promoting SDGs. Some studies have found that equality-related Goal like equitable quality education (SDG4), gender equality (SDG5) and reduce inequality (SDG10) are closely related to the overarching 2030 agenda (Pham-Truffert et al., 2020; Carl et al., 2022), because these 3 SDGs is highly relevant to human well-being and social stability, which are the key foundations for all SDGs.

Current literatures about SDGs linkages can primarily be categorized into qualitative evaluation like experts' knowledge or scoring assessment to quantify tradeoffs or synergies among SDGs in casual effect way and quantitative correlation analysis including Pearson's correlation analysis, spearman's correlation analysis or multiple factor analysis etc. to estimate SDG interactions. None of studies has constructed the statistical model with causality, this approach gap might produce some biased results when interpreting some interaction.

The overarching research question that Dr. Zhao focused on during his research stay at TUM was: "The role of equality (regional, social gender) on promoting SDGs through leveraging synergies and tackling trade-offs".

Dandan Zhao — Aalto University's research portal

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Development of a photocatalytic membrane system for removing trace organic chemicals

Water reuse has grown significantly in recent years in response to increasing demand for water. In Japan, non-potable water reuse has been implemented in several cities since the 1980s, mainly for urban applications such as toilet flushing, urban stream water augmentation, and landscape irrigation. To reduce cost and energy consumption, Japanese research groups have been developing promising technologies for water reuse, even though some of them are still at laboratory-scale development. Photocatalytic membrane can be a promising technology for removing trace organic chemicals (TrOCs) and antibiotic resistance genes in wastewater with lower chemical and energy consumption.

This study aims to develop a photocatalytic membrane system for removing trace organic chemicals in wastewater. The photocatalytic membrane system used in this study consists of a UV irradiation device and a flat-sheet ceramic microfiltration with TiO2 cake layer on its surface. The operational performance and removal performance of the photocatalytic membrane system was evaluated under different operational conditions.

The photocatalytic membrane exhibited high removal effect for 11 TrOCs in pure water but scavengers (DOC, nitrite and bicarbonate) in tap water and secondary effluent caused significant decrease in TrOCs removal. To overcome the scavenging effect and improve the removal performance, decreasing permeate flux was effective for tap water, and increasing UV intensity was more effective for secondary effluent due to the enhanced radical exposure. Effect of UV irradiation on membrane fouling control was also assessed during short-term operation. Fouling formation was mitigated by increasing UV intensity with 365nm due to the improved photodegradation and radical degradation of possible foulants. UV-LED lamp with 365 nm, which can provide high UV intensity with low power consumption, exhibited potential of decomposing the TrOCs in secondary effluent and controlling membrane fouling.

International Cooperation Partners

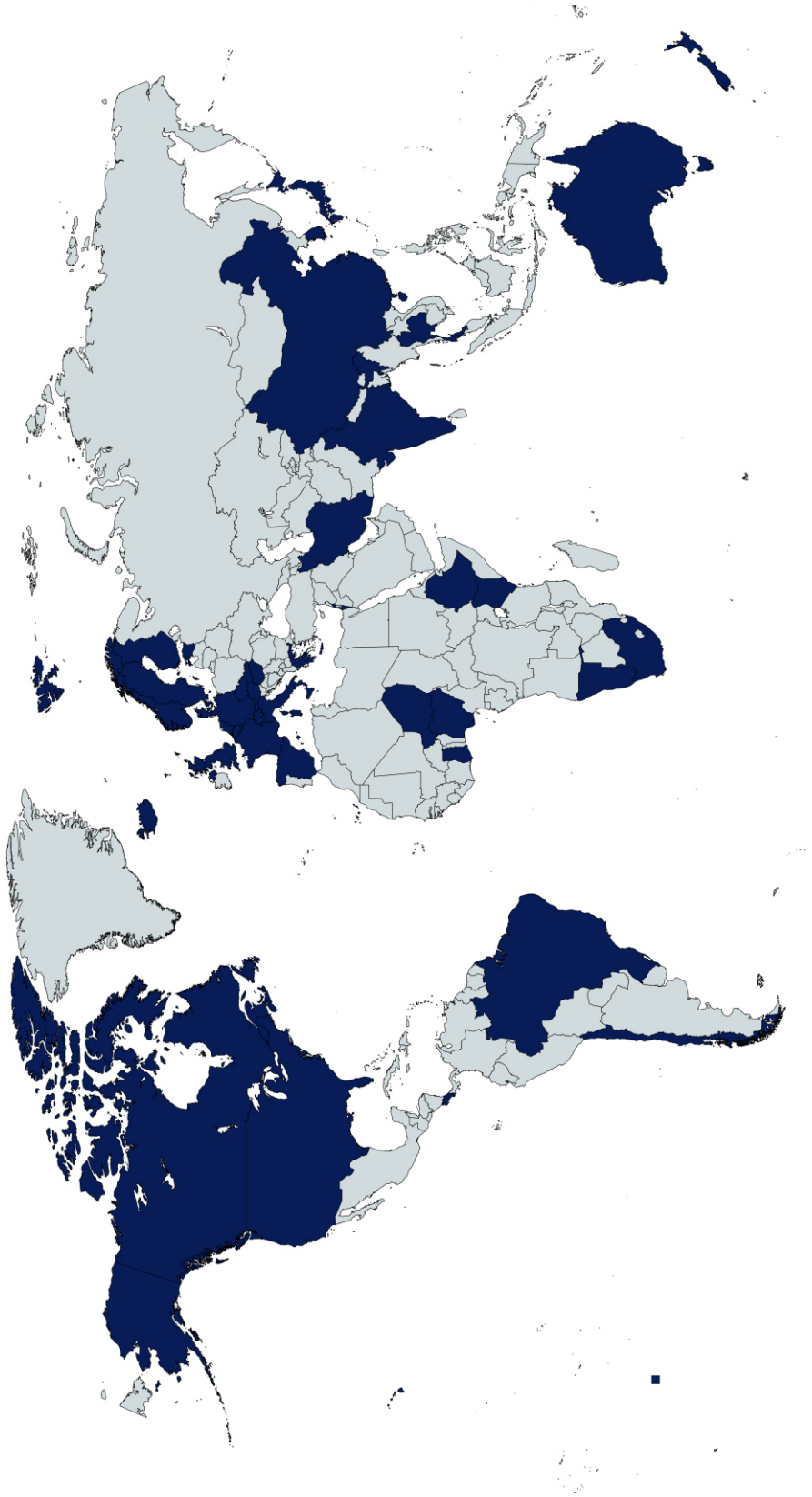

Figure 47. International partners.

Country	Institution
Australia	Murdoch University University of New South Wales University of Newcastle University of Queensland University of Southern Queensland
Austria	University of Natural Resources and Life Sciences, Vienna University of Vienna Vienna University of Technology
Brazil	Centro Federal de Educação Tecnológica de Minas Gerais Federal Center of Technological Education of Minas Gerais Instituto de Botânica Pontifícia Universidade Católica de Minas Gerais Universidade Federal da Bahia Universidade Federal de Minas Gerais Universidade Federal de Pernambuco Universidade Federal de Viçosa
Belgium	Flemish Institute for Technological Research
Canada	Université du Québec à Chicoutimi Université du Québec à Montréal University of Montreal
Chile	Universidad Andrés Bello
China	Beijing University of Technology City University of Hong Kong Nankai University Southwest Petroleum University China The University of Hong Kong Tsinghua University University of Chinese Academy of Sciences
Costa Rica	University of Costa Rica
Czech Republic	University of Chemistry and Technology, Prague
Denmark	Aarhus University European Environment Agency, Denmark Technical University of Denmark
Estonia	University of Tartu
Ethiopia	Addis Ababa Institute of Technology Addis Ababa Science and Technology University
Finnland	Aalto University Oulu University University of Jyväskylä
France	INRAE
Ghana	Kwame Nkrumah University of Science and Technology
Greee	Democritus University of Thrace National and Kapodistrian University of Athens
Hungary	University of Pannonia
Iceland	University of Iceland
India	Agharkar Research Institute Indian Institute of Science Bangalore Indian Institute of Technology Bombay
Iran	Isfahan University of Technology
Israel	Hebrew University of Jerusalem Tel Aviv University
Italy	University of Ferrara University of Brescia

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Country	Institution
Japan	Japan Agency for Marine-Earth Science and Technology National Institute for Environmental Studies of Japan The University of Tokyo Toho University University of Wakayama Yokohama National University
Kenya	Jomo Kenyatta University of Agriculture and Technology
Luxembourg	Luxembourg Institute of Science and Technology
Namibia	Namibia University of Science and Technology
Netherlands	Centraalbureau voor Schimmelcultures Delft University of Technology KWR Watercycle Research Institute Radboud University Nijmegen University of Amsterdam Wageningen University & Research
New Zealand	AgResearch
Niger	Abdou Monmouni University Niamey
Nigeria	Adekunle Ajasin University, Akungba Alex Ekwueme Federal University Ndufu-Alike Ikwo Bayero University Federal University Dutse Obafemi Awolowo University Redeemer's University University of Ibadan
Norway	Norwegian Geotechnical Institute University of Bergen University of Oslo University of Tromsø – The Arctic University of Norway
Slovakia	Environmental Institute, Slovakia
Singapore	Nanyang Technological University National University of Singapore
Spain	Catalan Institute for Water Research CSIC Polytechnic University of Catalonia University of Barcelona
South Africa	University of Cape Town Vaal University of Technology
South Korea	Chonnam National University Kangwon National University Seoul National University
Sweden	Chalmers University of Technology Lund University Stockholm University Swedish University of Agricultural Sciences University of Gothenburg Uppsala University
Switzerland	Forschungsanstalt Agroscope Reckenholz-Tanikon Swiss Federal Institute of Aquatic Science and Technology Swiss Federal Institute of Technology Lausanne Swiss Federal Institute of Technology Zurich University of Applied Sciences Northwestern Switzerland University of Zurich

Continues on the next page

Country	Institution
Thailand	Mae Fah Luang University
United Kingdom	Aberystwyth University Cranfield University University of Glasgow
United States	Arizona State University Colorado School of Mines Connecticut Agricultural Experiment Station Cornell University Drexel University Georgia Institute of Technology Institute of Ecosystem Studies Johns Hopkins University Massachusetts Institute of Technology Michigan State University Northwestern University Oklahoma State University San Diego State University Santa Ana Watershed Project Authority Southern Nevada Water Authority University of Arizona University of California at Berkeley University of California at Santa Barbara University of Colorado Boulder University of Michigan, Ann Arbor University of North Carolina at Chapel Hill University of Notre Dame University of Oxford University of York

National & International Committees

DWA Working Groups

Brigitte Helmreich is actively involved in various DWA working groups. She is deputy chairwoman of the **DWA technical committee ES-3** *"Plant-related planning"*, spokeswoman of the working group **DWA-ES-3.1** "*Infiltration of precipitation water*", member of the working groups **DWA-ES-3.11** "*Multifunctional surfaces*", **DWA-ES-3.7** "*Decentralized plants for precipitation water treatment*" and **DWA-ES-1.2** "*Substance inputs into drainage systems*". She is also an active member of the **DWA Technical Committee IG-2** "*Industry-specific industrial wastewater and waste"*.

Jörg E. Drewes is involved in the **DWA Technical Committee KA-8 "***Advanced Wastewater Treatment"*, in the **DWA Working Groups Biz 11.4** "*International Water Reuse*" as well as **KA-8.1** "*Anthropogenic Substances in the Water Cycle"*.

Benedikt Aumeier is an active member of the DWA working group KA-8.4, which is currently working on the DWA-M 1200 "Water reuse for agricultural and urban irrigation in Germany" in three parts. The publication of the yellow print is planned for 2024.

German Water Chemistry Society

Christian Wurzbacher is actively involved in the technical committee "*Pathogens and Antibiotic-Resistant Bacteria in the Water Cycle*", a subcommittee of the **German Water Chemical Society**. The group elaborates the current state of knowledge and perspectives in dealing with pathogens in the water cycle.
Benedikt Aumeier is actively involved in two technical committees of the German Water Chemistry Society: "Persistent, mobile and toxic (PMT) substances" and "Physical processes - membrane processes".

Drinking Water Commission

Jörg E. Drewes was appointed to a new term on the Drinking Water Commission at the Federal Ministry of Health/Federal Environment Agency in 2023 and acts as deputy spokesman there. The Drinking Water Commission advises the BMG and UBA on all aspects of the Drinking Water Ordinance (TrinkwV).

Journals – Editors

Christian Wurzbacher serves since 2016 as a Technical Editor of the journals *Fungal Biology*, *MycoKeys* and *Biodiversity Data Journal*.

Konrad Koch is member of the editorial board of the journals Bioresource Technology and Environmental Technology & Innovation. He was also a guest editor of the special issue of the magazine Bioresource Technology on the topic of “Anaerobic Digestion for Energy Security and Climate Change Mitigation” and of the magazine Environmental Technology & Innovation on the topic of “Organic carbon recycling for net zero emissions and sustainable organic carbon flow between urban and rural areas”.

Workshops & Other Activities

We are pleased that in 2023 the Roland Mall Foundation was able to award three talented students from the field of water and environment a scholarship of €500 per month for the entire standard period of study of the master's degree. The selected students Mattia Digiusto (Master of Environmental Engineering) and Lucas Bruckbeck (Master of Civil Engineering) were chosen based on their previous commitment and career.

50th Wastewater technology seminar - anniversary event for 50 years of wastewater research - impulses for the future

In 2023, we celebrated an important anniversary. We held the 50th Wastewater Technology Seminar (ATS) as a two-day conference in July at the Science Congress Center on the TUM Campus Garching. The 50th ATS anniversary was an opportunity to review the developments in the fields of drainage systems, rainwater management, biological wastewater treatment and advanced wastewater treatment, automation, resource recovery and water reuse over five decades with selected leading experts and the interested specialist public and to assess which trends and recommendations can be derived for the entire wastewater sector in the future. The following external experts enriched our program: Prof. Jurg Keller, Prof. Theo Schmitt, Stefan Brückmann, Prof. Karl-Heinz Rosenwinkel, Prof. Harald Horn, Prof. Susanne Lackner, Prof. Jörg Krampe, Prof. Eberhard Morgenroth, Prof. Heidrun Steinmetz, Prof. Martin Jekel, Prof. Thomas Wintgens, Dr. Lilian Buse, Dr. Nadine Scheyer and Prof. Martin Grambow.
This was a real highlight of the year! We would like to thank everyone who contributed to the success of this anniversary ATS.

Figure 48. Panel discussion of the 50th ATS.

12th Aqua Urbanica (2023)

Figure 49. Handing over the "baton" to next year's organizer, Graz University of Technology (Brigitte Helmreich and Günter Gruber)

We are pleased that we were able to organize Aqua Urbanica at the TU Munich location for the first time this year. The Aqua Urbanica is a scientific and practice-oriented event series that has focused on stormwater and mixed water management in urban areas since 2011. It is organized once a year by one of the six university D-A-CH cooperation partners (TU Munich, RPTU Kaiserslautern-Landau, TU Graz, University of Innsbruck OST Rapperswil and Eawag-ETH Zurich) together with the respective national association (DWA, ÖWAV and VSA). organized on a rotating basis.
The focus of this year's Aqua Urbanica 2023 on the topic "The water and pollutant conscious city - climate-adapted rainwater management meets pollutant problems" was on the water management opportunities and risks in adapting to climate change in urban areas in connection with the pollutant issue. Thanks to the diverse and exciting contributions, we were able to put together a varied program of lectures and posters and had a wide-ranging exchange of experiences and exciting discussions beyond individual national borders. The conference was reinforced by numerous manufacturers who presented current products on the topic. Overall, participants from municipalities, planning offices, university institutions and water management authorities from the entire D-A-CH region were represented, as well as various manufacturers from the area of urban drainage.

Sciencecyclists

In 2023, employees of the Chair of Urban Water Management cycled a total of over 7,339 km on their way to work. This corresponds to a CO2 saving of around 1.1 tons compared to a car or 2.8 tons compared to an airplane (economy class).

Company outing in November 2023

This year our company outing took place in the Bergkirchen bowling alley near Dachau on July 25th. A canoe tour on the Altmühl was actually planned, but it had to be canceled with short notice due to bad weather. Nevertheless, the atmosphere was great, unexpected bowling talents emerged and we ended the day together in the “Alter Wirt”. Special thanks to Daniel Nieß for the great organization given the short-term change in plans.

Figure 50. Company outing at the Bergkirchen bowling alley.

Upcoming Events

33rd Water Technology Seminar 2024

On June 20, 2023, the new Drinking Water Ordinance came into force in Germany, which implements key elements of the new EU Drinking Water Directive. Further requirements relate to the Drinking Water Catchment Areas Ordinance, for which only a draft version is available to date and in which the concept of risk management is further specified. The requirements for operators of water supply systems and health authorities, which are regulated in these ordinances, are considerable.

New requirements relate to a comprehensive risk-based assessment of the catchment area, the water treatment plant and the distribution networks through to the consumers. In addition, there are adjustments to operating parameters and innovations in chemical water quality parameters and stricter limits as well as some microbiological parameters, e.g. somatic coliphages, PFAS, bisphenol A, lead, chromium or arsenic.

In our seminar, we therefore want to discuss the implementation of these requirements in practice with proven experts, especially under the boundary conditions of the structure of the Bavarian drinking water supply.

The seminar is primarily aimed at local authorities, drinking water suppliers, health authorities, state institutions, planning offices, consultants and experts.

We look forward to an interesting event, which will be offered as a virtual seminar on February 28, 2024.

51st Wastewater Technical Seminar 2024

The 51st Wastewater Technology Seminar (ATS) will be dominated by the new EU Urban Wastewater Treatment Directive (EU-UWWTD), which, with its ambitious objectives, will provide groundbreaking and far-reaching impetus for wastewater treatment and water reuse. It therefore represents a cornerstone of the European Green Deal. At the ATS, we will focus on the new legal framework, the handling of mixed water, the quaternary treatment stage (elimination of trace substances), the goal of energy neutrality and other new requirements and implications. We are inviting renowned experts to present the revision to us and discuss the implications with us. The 51st ATS will take place on July 3, 2024 in the “Bürgerhaus der Stadt Garching” in Präsenz. Information on registration and for companies/exhibitors can be found online: http://sww.bgu.tum.de/ats . We look forward to seeing you there!

Publications

Peer-reviewed Journal Articles

1) Adeleye, A.T.; John, K.I.; Helmreich, B. (2023): Recent strategies for the remediation of Ivermectin from the environment: A critical review. Journal of Water Process Engineering 56, 104334.
2) Al-Azzawi, M.S.M.; Kunaschk, M.; Mraz, K.; Freier, K.P.; Knoop, O.; Drewes, J.E. (2023): Digest, stain and bleach: Three steps to achieving rapid microplastic fluorescence analysis in wastewater samples. Science of The Total Environment 863, 160947.
3) Bardi, M.J.; Mutunga, J.M.; Ndiritu, H.; Koch, K. (2023): Effect of pyrolysis temperature on the physiochemical properties of biochar and its potential use in anaerobic digestion: A critical review. Environmental Technology & Innovation 32, 103349.
4) Bardi, M.J.; Vinardell, S.; Astals, S.; Koch, K. (2023): Opportunities and challenges of adding trace elements in anaerobic digestion - A critical review. Renewable and Sustainable Energy Reviews 186, 113689.
5) Bayode, A.; Anthony, E.T.; Ore, O.T.; Moses O.A.; Koko, D.T.; Unuabonah, E.I.; Helmreich, B.; Omorgie, M.O. (2023): A review on the versatility of Carica papaya seed-an agrogenic waste for the removal of organic, inorganic and microbial contaminants in water. Journal of Chemical Technology & Biotechnology, 98 (9), 2095-2109.
6) Bayode, A.; Folorunso, M.; Helmreich, B.; Omorogie, M.O. (2023): Biomass-tuned reduced graphene oxide@Zn/Cu: Benign materials for the cleanup of selected non-steroidal anti-inflammatory drugs in water. ACS Omega 8 (8), 7956-7967.
7) Behringer, M.; Hilbig, H.; Helmreich, B.; Machner A. (2023): Effect of the pH on the interaction of hydrotalcite with dyes from textile wastewater. Ce/Papers 6, 194-200.
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Other Journal Articles and Book Contributions

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6) Drewes, J.E. (2023): Auswirkungen des Klimawandels auf die Versorgung mit Wasser. Bundesärztekammer, Ausschuss 'Klimawandel und Gesundheit', 13 November 2023, Berlin, Germany.
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13) Drewes, J.E. (2023): Siedlungswasserwirtschaft – technische Entwicklungen und Optimierung bei der Abwasserbehandlung. Ökoworld Beiratstagung, 25 September 2023, Berlin, Germany.
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16) Drewes, J.E. (2023): Umsetzung der EU-Wasser-Wiederverwendungsverordnung in Deutschland. Workshop Wiederverwendung von gereinigtem Wasser, TU Wien, 21-22 February 2023, Vienna, Austria.
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31) Gondhalekar, D. (2023): Bonn till Now: The Triple Crisis and the Evolution of the WEF Nexus. Keynote speech at GIZ Nexus Dialogue: Breaking Silos for a Sustainable Tomorrow, 19 June 2023, Bonn, Germany.
32) Gondhalekar, D. (2023): GREEN SAHEL: Augmenting water, energy and food security in the Sahel Region with an integrated ecosystem services Nexus approach. Eighteenth International Conference on Interdisciplinary Social Sciences, Oxford Brookes University, 19 July 2023, Oxford, UK.
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35) Gondhalekar, D.; A. Narayan, M. Lahmouri; J.E. Drewes & C. Schwaller (2023): Estimating Potential of Greenhouse Gas Emissions Reduction Using Water-Energy-Food Nexus Approach In Leh Town, Ladakh, India. 13th IWA International Conference on Water Reuse, 15-19 January 2023, Chennai, India.

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37) Helmreich, B. (2023): Baumrigolen als Versickerungssysteme? - Eignung und Einschränkungen. Aqua Urbanica 2023, 9-10 October 2023, Garching, Germany.

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40) Helmreich, B. (2023): Dezentrale Behandlung von Niederschlagswasser – Multifunktionale Versickerungsmulden im Siedlungsraum. Seminar Biozide in Baumaterialien – Von wissenschaftlicher Erkenntnis zu praktischen Handlungsmöglichkeiten, Bayerisches Landesamt für Umwelt, 29-30 June 2023, Augsburg, Germany.

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50) Koch, K.; Astals, S.; Hafner, S.; Weinrich, S. (2023): Better BMP – Free resources for improving the quality of biochemical methane potential tests. 6th International Conference on Monitoring & Process Control of Anaerobic Digestion Processes, 22-23 March 2023, Leipzig, Germany.

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56) Schwaller, C.; Gondhalekar, D.; Narayan, A.; Lahmouri, M.; Drewes, J.E. (2023): Estimating potential of greenhouse gas emissions reduction using Water-Energy-Food Nexus approach in Leh Town, Ladakh, India. 13th IWA International Conference on Water Reuse, 15-19 January 2023, Chennai, India.

57) Steindl, M.; Dandikas, V.; Lichti, F.; Höcherl, S.; Koch, K. (2023): Methane production rate from blanks influences parameter estimation during BMP tests. 6th International Conference on Monitoring & Process Control of Anaerobic Digestion Processes, 22-23 March 2023, Leipzig, Germany.

58) Stinshoff, P.; Helmreich, B. (2023): Multifunctional infiltration swales - Optimized topsoil layer with substrate amendments for enhanced urban stormwater treatment. Novatech, 3-7 July 2023, Lyon, France.

59) Stinshoff, P.; Helmreich, B. (2023): Multifunktionale Versickerungsmulden im Siedlungsraum – Behandlung von Verkehrsflächenabflüssen mit angepasster bewachsener Bodenzone. Aqua Urbanica 2023, 9-10 October 2023, Garching, Germany.

60) Uchaikina, A.; Mitranescu, A.; Kau, A.; Kluge, M.; Wurzbacher, C. Stange, C.; Ho, J.; Drewes, J.E. (2023): Abwasserepidemiologie für SARS-CoV-2 Biomarker: tageszeitliche Schwankungen der Biomarker in Abhängigkeit von der Gemeindegröße. Wasser 2023, 15-17 March 2023, Augsburg, Germany.

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62) Wurzbacher, C. (2023): Distribution and identity of freshwater fungi in the environment. AMC2023, 10-13 October 2023, Busan, South Korea.

63) Wurzbacher, C. (2023): Passports for dark aquatic taxa. AMC2023, 10-13 October 2023, Busan, South Korea.

64) Wurzbacher, C.; Drewes, J.E.; Ho, J.; Agrawal, S.; Lackner, S.; Schoth, J.; Bastian, D.; Weber, F.-A (2023): SARS-CoV-2 Monitoring – Gesamtheitliche Datenauswertung von mehrjährigen Messreihen aus drei BMBF-Vorhaben. 56. Essener Tagung, 7-9 March 2023, Aachen, Germany.

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66) Zhiteneva, V.; Mosher, J. Gerba.; C.; Rauch-Williams, T.; Drewes, J.E. (2023): Improving Implementation of Managed Aquifer Recharge (MAR) Systems by Utilizing Updated Pathogen Removal Knowledge. 13th IWA International Conference on Water Reuse, 15-19 January 2023, Chennai, India.

Theses

Doctoral Dissertations

1) Feickert Fenske, Carolina: Biological H_2/CO_2 Methanation in Trickle Bed Reactors – Toward Industrial Application
2) Ponzelli, Michele: Design of hybrid nano-engineered bioprocesses for wastewater treatment
3) Reichel, Julia: Identification of polymer types, additives and simultaneous quantification of trace organic chemical sorption behavior on subµ-particles in environmental samples
4) Sperle, Philipp: The potential of UVC-irradiation using LEDs as an (in situ) biofouling control strategy in reverse osmosis membrane systems

Master's Theses

1) Adegbenle, Kowiyu Adeniyi: Entwurf eines Prototyps einer Regenwassersammelanlage für das Dorf Dar es Salaam, Sahel-Region, Niger.
2) Ahoor, Danika: Zellen- und Nährstoffrückhalt in der biologischen Methanisierung.
3) Bergmann, Felix: Untersuchungen zur Brauchwassernutzung im Bereich des Vilstalsees bei Marklkofen.
4) Busse, Lilian: Behandlung von belastetem Verkehrsflächenabfluss in multifunktionalen Versickerungsmulden durch eine technisch angepasste bewachsene Bodenzone - Untersuchungen im halbtechnischen- und Pilotmaßstab.
5) Contreras Vomend, Fernando Mario: Entwurf eines Membranbioreaktors für Kläranlagen in touristischen alpinen Gebieten unter Verwendung eines stationären Berechnungsmodells durch Anpassung von Schlammmasse und -alter.
6) Franz, Benedikt: Risikobewertung wassergefährdender Stoffe im Einzugsgebiet eines Spitzenförderwerks der Münchner Schotterebene und Untersuchung anthropogener Spurenstoffe im Trinkwasser.
7) Heimann, Amelie: Wirtschaftlichkeitsanalyse einer Power-to-Gas Anlage in Deutschland.
8) Henn, Yannik: Schwermetallremobilisierung von Filtermaterialien aus dezentralen Behandlungsanlagen für Verkehrsflächenabflüsse - Vergleich von Labor- und Feldproben.
9) Ikusemoro, Timilehin: Strategische Planung für die Smart City Entwicklung mit Hilfe des Nexus-Ansatzes; eine Fallstudie des Staates Lagos, Nigeria.
10) Kirzeder, Franz: Biogasaufbereitung in einem Rieselbettreaktor mit biologischer Methanisierung - Untersuchung und Herausforderungen im Langzeitbetrieb unter realen Anwendungsbedingungen.
11) Kunder, Pratik: Automatische Schätzung der freien Gibbs-Energie für Metaboliten in einem metabolischen Netzwerk.
12) Lei, Huiyi: Untersuchung der TOrCs-Biotransformation in sekundären Abwässern unter oligotrophen und oxischen Bedingungen.
13) Melhem, Mohannad: Ein nachhaltiger Managementansatz zur Optimierung der Wasserressourcen für die bestehende Wasserversorgungsinfrastruktur in Jordanien.
14) Meti, Burak: Eine umwelttechnische Analyse zur Minderung des Gefrierprozesses in den Rohren, die für die Ice Stupa Technology in Ladakh, Indien, verwendet werden.
15) Mraz, Christina: Biologischer Abbau von markierten Ozonierungsprodukten: Anwendung einer neuen Markierungstechnik zur Untersuchung von Biotransformationsprodukten und deren Entfernung in Abwasserbehandlungsprozessen.
16) Noormal, Nasrat Maiwand: Schätzung der Faktoren, die das Potenzial zur Einführung der Biogastechnologie in Entwicklungsländern bestimmen, am Beispiel Afghanistans.

17) Ortega Fuerte, Andrea: Cradle-to-Gate-LCA für das Benchmarking der PFAS-Entfernung mit membranbasierter Technologie.
18) Ozluer, Meltem: Untersuchung der Rolle der Zusammensetzung des mikrobiellen Kulturmediums bei der Biotransformation von TOrCs durch Anilinabbauer.
19) Pollok, Daniel: Verbesserung der Bewertung des thermischen Komforts im Freien in städtischen Gebieten durch Einbeziehung der Wasserverfügbarkeit in Mikroklimamodelle: eine systematische Literaturrecherche.
20) Qureshi, Areeba Ilyas: Entwurf eines dezentralen Abwasserbehandlungssystems mithilfe von GIS-Modellierung zur Förderung von WEF-Nexus in der Region: eine Fallstudie in Leh City, Ladakh, Indien.
21) Späth, Alina: Gegenüberstellung der Regelwerke DWA-M 153 und DWA-A 102 anhand von Beispielen im Tegernseer Tal.
22) Straub, Julian: Einsatz einer Nanofiltrationsmembran zur Abscheidung von metabolisch erzeugtem Wasser aus einem Rieselbettreaktor.
23) Strebel, Annika: Charakterisierung von Azofarbstoffen und ihre Entfernung aus Textilabwässern durch Adsorption: Ein Überblick.
24) Urgibl, Christina: Modernisierung der Kläranlage der Gemeinde Schwindegg - Objektplanung LP 2 und 3.
25) Wang, Yifang: Einfluss der CO2-Anreicherung auf die Biogaserzeugung und -zusammensetzung bei hoher Substratzugabe.

Study Projects

1) Asefi, Massihullah: Entwurf eines ASTR-Systems als Regenwassernutzungsstrategie zur Grundwasserneubildung unter Verwendung von GIS in Dar, Niger.
2) Bertram-Mohammadi, Poojesh: Auswirkungen von Multi-Barrieren-Behandlungstechnologien mittels Pre- und Post-Ozonierung in Kombination mit einer keramischen Ultrafiltrationsmembran auf die Entfernung von MS2-Bakteriophagen.
3) Fuchs, Sophia: Analyse des Auslaugverhaltens von Folien- und plattenförmigen Gründachmaterialien mit der dynamischen Oberflächenauslaugprüfung (DSLT).
4) Fung, Jonas: Kombinierte aerobe-anaerobe Behandlung von Speiseresten.
5) Gangal, Advait: Modellierung der Inaktivierungsleistung eines UVC-LED Durchflussreaktors unter Verwendung von COMSOL Multiphysics.
6) Gupta, Saniv: Boden-Wasser-Pflanzen-Nexus und Klimawandel.
7) Heimann, Amelie: Ansätze für die Integration eines Membransystems zur Entfernung des metabolischen Wassers in Methanisierungsreaktoren.
8) Hilpert, Andre: Open-Access-Analysetools für Urban WEF Nexus im Stadtmaßstab – Überprüfung.
9) James, Arsha: Analyse des Versickerungsverhaltens von Gründachsubstraten mittels eines Säulentests nach DIN19528.
10) Krebs, Mathilda: Anpassung von Städten an den Klimawandel – das Schwammstadtprinzip – Sanierung von Grundstücksentwässerungsanlagen am Beispiel eines Einfamilienhauses in München.
11) Kuz'menko, Andrej: Bewertung des Treibhausgas-Reduktionspotenzials im Lebensmitteleinzelhandel in München.
12) Lee, Hans: Einfluss von Natriumbicarbonat auf die Biogasproduktion aus verschiedenen Substraten im Batch-Test.
13) Leon Caguenas, Maria: Einsatz von CO2 zur Verbesserung der anaeroben Vergärungsleistung.
14) Mani, Jefi Sara: Bewertung des Auslaugungsverhaltens von mineralischen und organischen Substraten für den Einsatz in städtischen Bioinfiltrationsmulden zur Regenwasserbehandlung.

15) Ng, Peng Siang: Auswirkung der Nährstoffrückgewinnung auf den Kohlenstoff-Fußabdruck des Abwasseraufbereitungssystems von Singapur.
16) Oberem, Caroline: Auswertung halb-technischer Versuche von Versickerungsmulden mit Substratbeimengung - Optimierter Rückhalt von Bioziden und Kupfer aus urbanen Niederschlagsabfluss durch die bewachsene Bodenzone.
17) Qureshi, Areeba Ilyas: Der Einfluss von Wasserstoff auf die Methanausbeute bei der anaeroben Co-Vergärung durch Anreicherung von CO2 bei höheren Raumbelastungen.
18) Radwan, Mohamed: Entwicklung von Python-Tools für die Analyse und Validierung von PFAS-Adsorptionsdatensätzen.
19) Schorer, Elisa: Entwicklung eines Dashboards für abwasserbasierte Epidemiologie für SARS-CoV-2-Biomarker zur internen Verwendung im Gesundheitsamt des Berchtesgadener Landes.
20) Stöhr, Fabian: Datenaufbereitung und Zustandsbewertung als Grundlage für eine Sanierungskonzeption des Sammelkanalnetzes eines Abwasserverbandes.
21) Vilabrera, Naim: Der Einfluss der Kohlenstoffkonzentration im Abwasser auf das Wachstum von mikrobiellen Modellgemeinschaften und den biologischen Abbau von organischen Spurenstoffen.
22) Yıldız, Buse: TUM ist toll - jetzt wird's COOL: Auswirkungen einer effizienteren Beleuchtung auf dem TUM-Campus auf die Treibhausgasemissionen.
23) Zhang, Xiaojun: Konstruktion von Gründächern im Pilotmaßstab für Auslaugversuche von Wurzelschutzbahnen.
24) Zhao, Zhiyuan: Einfluss von Natriumbicarbonat auf die Biogasproduktion aus verschiedenen Substraten im Batch-Test.

Bachelor's Theses

1) Barth, Elisabeth: Möglichkeiten zur alternativen Bewässerung des urbanen Grüns in Städten mit Hitze- und Wasserstress
2) John, Julia: Filtermaterialien zur Entfernung von Schadstoffen aus urbanen Regenwetterabflüssen
3) Manninger, Felicia: Auswirkungen des Klimawandels auf die Wasserversorgung Deutschlands
4) Lirapirom, Akradeth: Literaturrecherche zu Möglichkeiten des Regenwassermanagements bei hohen Grundwasserständen
5) Kovacs, Hannah: Konzeptentwicklung für Grauwasserrecycling als alternative Wasserressource in der Jugendfreizeitstätte beim Bauvorhaben Bayernkaserne/Neufreimann der Landeshauptstadt München
6) Mäckel, Sophie: Untersuchung alternativer Konzepte für eine weitergehende Spurenstoffelimination auf kleinen Kläranlagen (2.000 – 10.000 EW)
7) Sudjito, Alexander Ando: Eine Literaturrecherche zum Einfluss von verschiedenen Wurzelsystemen auf den Schadstoffrückhalt in naturnahen Behandlungsanlagen von Niederschlagswasser
8) Riedler, Philipp: Anpassungsfähigkeit alternativer Konzepte für eine weitergehende Spurenstoffelimination unter wechselnden Randbedingungen bei kleinen Klaranlagen (2.000 – 10.000 EW)

Dissertations and Awards

Congratulations to **Dr.-Ing. Carolina Feickert Fenske** for the successful defense of her doctoral thesis on October 13, 2023. Her thesis, entitled "Biological H2/CO2 Methanation in Trickle Bed Reactors – Toward Industrial Application", was reviewed by Prof. Marika Kokko (Tampere University, Finland), Mr Prof. Lars Ditlev Mørck Ottosen (Aarhus University, Denmark) and Mr. PD Konrad Koch. The chairwoman of the commission was Prof. Brigitte Helmreich.

Figure 51. Doctoral committee of Dr.-Ing. Carolina Feickert Fenske.

Figure 52. Doctoral committee of Dr. rer. nat. Julia Reichel.

Congratulations to **Dr. rer. nat. Julia Reichel** for the successful defense of her doctoral thesis on December 1, 2023. Her work entitled "Identification of polymer types, additives and simultaneous quantification of trace organic chemical adsorption behavior on subμ-particles in environmental samples" was reviewed by Mr. PD Thomas Letzel (formerly TUM), Prof. Martin Jekel (TU Berlin) and Prof. Jörg E. Drewes. The chairman of the commission was Prof. Martin Elsner (TUM).

Congratulations to **Dr.-Ing. Michele Ponzelli** for the successful defense of his doctoral thesis on December 11, 2023. His thesis entitled "Design of hybrid nano-engineered bioprocesses for wastewater treatment" was supervised by Prof. Maite Pijuan (University of Girona, Spain), Prof. Sasha D. Hafner (Aarhus University, Denmark) and Prof. Jörg E. Drewes reviewed. The chairman of the commission was Prof. Sebastià Puig Broch (University of Girona, Spain), as it is a double degree from TUM and the University of Girona.

Figure 53. Doctoral committee of Dr.-Ing. Michele Ponzelli.

Figure 54. Doctoral committee of Dr.-Ing. Philipp Sperle.

Congratulations to **Dr.-Ing. Philipp Sperle** for the successful defense of his doctoral thesis on December 18, 2023. His thesis entitled "The potential of UVC-irradiation using LEDs as an (in situ) biofouling control strategy in reverse osmosis membrane systems" was supervised by Prof. Karl Linden (University of Colorado Boulder, USA), Prof. Hans Vrouwenvelder (King Abdullah University of Science and Technology, Saudi Arabia) and Prof. Jörg E. Drewes. The chairman was Prof. Brigitte Helmreich.

We are happy and congratulate **Dr.-Ing. Thomas Lippert**, who was awarded the Willy Hager Prize 2022 for his doctoral thesis entitled "Sewage sludge disintegration using innovative ultrasound reactors with surface transducers - Performance assessment and optimization of operating conditions". The prize is awarded by the Willy Hager Foundation for outstanding work by young university scientists in the field of water and wastewater treatment in Germany. The prize is normally presented at the annual meeting of the Water Chemical Society within the GdCh. Since Mr. Lippert was unfortunately unable to attend this event in person, the certificate was handed over during a later visit by his supervisor PD Konrad Koch.

Figure 55. Handover of the certificate by the supervisor PD Konrad Koch to the award winner Dr.-Ing. Thomas Lippert (now a postdoc at Northwestern University, USA).

Figure 56. from left to right: Dr. Pablo Vega Garcia, Mr. Michael Mall (Chairman of the Roland Mall Family Foundation and member of the jury) and Ms. Kim Lange.

Dr. Pablo Vega Garcia received the Mall Environmental Prize Water for outstanding dissertations on June 14, 2023. He completed his doctorate with us last year on the topic: "Development of a model to assess the environmental properties of common outdoor plasters and mortars". Ms. M.Sc. Kim Lange won the Mall Environmental Prize for outstanding master's theses. The topic of her thesis, with which she completed her master's degree in "Environmental Engineering," was "Comparative study of the annual water balance in the context of

climate adaptation in a residential area in Ingolstadt." The two prizes were ceremoniously presented on June 14, 2023 in Donaueschingen.

Dr. Christoph Schwaller, who received his doctorate at the chair in December 2022, received the **Civil and Environmental Engineering Department Prize** for his outstanding doctoral thesis: Agricultural irrigation demand modeling and assessment of membrane ultrafiltration alone or hybridized with inline dosed powdered activated carbon for non-potable water reuse applications get TUM. The award was presented on Department Day on July 14, 2023.

Prof. Dr.-Ing. Jörg Drewes received the **Bavarian State Medal** for his outstanding contributions to the environment. Climate change is changing the availability and distribution of water across the globe. In order to ensure a secure water supply in the future, we have to think of new ways. The research of Prof. Dr.-Ing. Jörg Drewes outlines these paths. The medal was presented by the Bavarian State Minister Thorsten Glauber.

Figure 57. State Minister Thorsten Glauber (left) and Prof. Dr. -Ing. Jörg Drewes.

Teaching

The Chair of Urban Water Systems Engineering offers a wide range of different courses for the Bachelor study program *Environmental* Engineering and *Civil Engineering* as well as for the Master programs *Environmental Engineering*, *Civil Engineering*, *Ecological Engineering,* and *Sustainable Resource Management*. The emphasis of these courses is placed on water chemistry, advanced water treatment, energy recovery from wastewater, water recycling as well as conceptual design for sustainable water supply and wastewater disposal systems for urban areas. In 2023, the following lectures were offered:

Summer Term

Bachelor

- Kreislaufwirtschaft und Werkstoffe für nachhaltiges Bauen: Koch, Konrad
- Mikrobiologie: Wurzbacher, Christian
- Projektkurs Siedlungswasserwirtschaft: Drewes, Jörg
- Thermodynamik und Energietechnik Übung: Hübner, Uwe
- Umweltanalytik: Helmreich, Brigitte; Petz, Susanne
- Umweltrecht: Spieler Martin (TUM-Lecturer)

Master/PhD

- Advanced Water Treatment Engineering and Reuse: Drewes, Jörg
- Anaerobic Treatment and Energy Recovery: Koch, Konrad
- Bewirtschaftung von Kanalnetzen und Regenwassermanagement: Helmreich, Brigitte
- Colloquium für PhD and Master Students – Proactiv: Drewes, Jörg; Helmreich, Brigitte; Koch, K., Wurzbacher, Christian; Keilman-Gondhalekar, Daphne; Sotorff, Ignacio
- Gute Wissenschaftliche Praxis: Koch, Konrad
- Hydrochemistry Laboratory: Helmreich, Brigitte; Sottorff, Ignacio; Ernle, Lisa; Koch, Konrad
- Industrial Wastewater Treatment and Reuse: Helmreich, Brigitte
- PhD Seminar SiWaWi: Drewes, Jörg; Sottorff, Ignacio
- Planning the Urban Water-Energy-Food Nexus, lecture & project: Keilman-Gondhalekar, Daphne
- Unit Operations Laboratory on Advanced Water Treatment: Hübner, Uwe
- Wastewater Treatment: Koch, Konrad
- Scientific Methods and Presentation Skills: Koch, Konrad

Winter Term

Bachelor

- Siedlungswasserwirtschaft Grundmodul: Helmreich, Brigitte; Koch, Konrad
- Verfahrenstechnik: Böhm, Bernhard (TUM-Lehrbeauftragter); Koch, Konrad
- Verfahrenstechnik Übung: Böhm, Bernhard (TUM-Lehrbeauftragter); Koch, Konrad

Master/PhD

- Aquatic Microbiology: Wurzbacher, Christian
- Design and Operation of Wastewater Treatment Plants: Athanasiadis, Konstantinos (TUM-Lehrbeauftragter); Böhm, Bernhard (TUM-Lehrbeauftragter)
- Doktoranden und Masteranden Kolloquium – Proaktiv: Drewes, Jörg; Helmreich, Brigitte; Koch, Koch, Wurzbacher, Christian; Keilmann-Gondhalekar, Daphne; Sottorff, Ignacio
- Engineered Natural Treatment Systems: Aumeier, Benedikt
- Gute Wissenschaftliche Praxis: Koch, Konrad
- Hydrochemistry Laboratory: Helmreich, Brigitte; Sottorff, Ignacio; Heim, Carolin; Koch, Konrad
- Hydrochemistry: Helmreich, Brigitte
- Modeling of Aquatic Systems: Koch, Konrad
- PhD Seminar SiWaWi: Sottorff, Ignacio; Drewes, Jörg
- Planungs- und Genehmigungsverfahren nach deutschem und europäischem Wasserrecht: Spieler, Martin (TUM-Lehrbeauftragter)
- Scientific Methods and Presentation Skills: Möckel, Rolf; Drewes, Jörg
- Water and Wastewater Treatment Engineering: Drewes, Jörg

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Friends of the Chair

The Development Fund of the Chair of Urban Water Systems Engineering e.V. at TUM is a non-profit organization to support research and teaching at the chair.

Membership is open to anyone who supports the goals of the foundation. Funds provide seed grants for research efforts:

- Supplement to cover printing costs of scientific reports/publications
- Publish the book series “Reports of Urban Water Systems Engineering”
- Support teaching funds
- Support travel fellowships for doctoral candidates and graduate students
- Partially support of research infrastructure
- Facilitate scientific meetings and workshops in the area of water treatment and wastewater treatment and reclamation

We publish our annual report forum to keep our members informed regarding activities at the Chair of Urban Water Systems Engineering.

In order to fulfill these tasks, we depend on donations. Thus, we welcome financial and in-kind contributions. We do not charge a membership fee.

Donations can be transferred electronically to the following account at the Postbank München (IBAN: DE04 7001 0080 0034 9498 02, BIC: PBNKDEFF). All donations are tax-deductible.

The office of the Development Fund is led by Raphaela Hoffmann.

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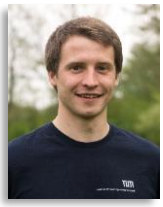

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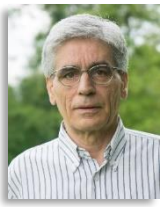

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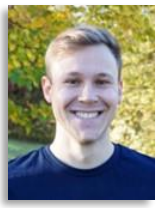

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