forum 92

Newsletter of the Chair of Urban Water Systems Engineering

Annual Report of the Chair of Urban Water Systems Engineering

2021

Chair of Urban Water Systems Engineering

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Foreword

Dear Friends,

we are now entering our third Corona year which probably no one would have thought possible and the new normal has changed many processes and drastically reduced face-to-face encounters. Although we had hoped it would not happen, we are now teaching our students largely in online mode for the fourth semester in a row. Unfortunately, this is studying and learning with significant sacrifices, and we are sorry for our students.

Despite many challenges, we are nevertheless grateful for a productive year at the chair with remarkable graduations of our PhD students, a very good development of our external funding and very exciting research activities. With regard to the pandemic, we were very busy last year with measurement of corona biomarkers in wastewater and were in close exchange with municipalities, health authorities, the RKI and federal ministries. Our staff was very active in publishing their findings in scientific publications and sharing them with the national and international scientific community in virtual meetings and lectures.

We are happy for Dr.-Ing. Uwe Hübner for the successful completion of his habilitation. We are also proud of Dr.-Ing. Steffen Rommel, Dr. rer. nat. Rofida Wahman, Dr.-Ing. Jochen Bandelin and Dr.-Ing. Thomas Lippert for the successful completion of their doctorate degrees this year. A special honor went to Dr.-Ing. Sema Karakurt-Fischer, who was awarded the 2021 Doctoral Prize of the Association of Friends of the TU Munich e.V. for her doctoral thesis last year. Congratulations once again!

With this issue, I am very pleased to be able to present you with our Annual Report 2021 to give you a little insight into our activities. In 2021, we were also strengthened by new employees, who introduce themselves to you in this annual report along with their other colleagues.

2021 was also associated with major organizational changes for TUM. Our Faculty of Civil, Geo-Environmental Engineering was terminated on October 1, 2021, and we are now organized in a new TUM School of Engineering and Design together with other faculties of architecture, mechanical engineering, aerospace engineering, electrical engineering and process engineering as part of the new Excellence Initiative. Within this school there are now eight departments and we find ourselves in the Department of Civil and Environmental Engineering. This reorganization comes not surprisingly with corresponding birth pains.

Similar to many other events, we held this year's Wastewater Technical Seminar (ATS) virtually due to the pandemic. In 2022, we will resume our seminar series with the 32nd Water Technical Seminar (WTS) as a virtual event with the topic "Pathogens and antibiotic-resistant bacteria in the water cycle", which was organized under the leadership of Dr. Christian Wurzbacher, on February 23, 2022. This topic is not only topical in Bavaria but also in Germany and we have been able to attract leading speakers. The 49th ATS is planned for July 5, 2022, and this time it will be dedicated to the topic "Water Reuse - Potential and Applications in Germany" under my leadership. The programs of these events can be found in this issue of FORUM and on our website. There you can also register online (www.cee.ed.tum.de/sww). We would be delighted to learn of your interest in these events.

In our 'core business', the Chair again made significant contributions to the education of students in the Bachelor's programs in Environmental Engineering and Civil Engineering as well as in the Master's programs in Environmental Engineering, Civil Engineering and Sustainable Resource Management. In addition to a large number of lectures, exercises and practical courses, the staff of the chair supervised an impressive number of 90 master's theses, student research projects and bachelor's theses.

In addition to my duties as the head of the Chair, I am serving as the Academic Program Director for the Environmental Engineering program and its further development at TUM. I am also involved in the International Water Association (IWA) and the German Advisory Council on Global Change (WBGU). At the WBGU, we are currently preparing a new main report with a focus on 'Planetary Health' (read more at: ttps://www.wbgu.de/en/publications/publication/discussionpaper-health).

On behalf of my staff, I would like to thank you very much for your support and interest in our students and our work. In particular, we would like to thank you for the support of our association ‘Friends of our Chair’, which makes a very important contribution to the education of our graduate students and undergraduates by funding travel to conferences and research grants.

We would be very happy if we could provide these supports for our PhD students, graduates and undergraduates again this year through your donation.

We wish you much confidence, a successful year and much pleasure in reading.

Yours,

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Research Center

The mission of the research center at the Chair of Urban Water Systems Engineering 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.

The research center is directed by Prof. Brigitte Helmreich.

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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. Susanne Petz, the trace compounds analysis unit led by Dr. Oliver Knoop 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 (Figure 2), organic parameters can be further determined using 3-D fluorescence and UV spectroscopy and measured quantitatively with the TOC analyzer. For analysis of anions either photometric test methods or ion chromatography are available. Determination of metals is carried out using atomic absorption spectrometry.

Figure 2: Determination of single and sum parameters through cuvette tests using the HACH-photometer.

We are also able to determine the particle size distribution of a wide range of materials by means of dry sieving.

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

Due to the increasing frequency of extreme weather events such as heavy rain events and periods of drought, climate change poses major challenges for urban drainage. Therefore, adaptation strategies as a reaction to the consequences of climate change are increasingly coming to the fore. Even when planning new quarters or densifying districts in settlements, it is important to integrate all actors in the grey, green and blue infrastructure into the planning from the very beginning. A new research project therefore deals with the topic of climate-friendly building, in which all these actors are involved from the start. Together with other research partners, we scientifically accompany ten selected model projects in Bavaria, in which, among other things, the local water balance is to be supported with selected elements of the water-sensitive city.

Another research project deals with the optimization of vegetated infiltration swales, which are also an important tool for the water-sensitive city. The focus here is not only on drainage security and the retention of pollutants, but also on biodiversity and insect protection.

Figure 5: Example of a green roof as a tool for the water-sensitive city.

Qualitative aspects of stormwater runoff have been the focus of the working group for many years. Therefore, in 2021, the complexation of heavy metals with biocides and pesticides from roof and facade runoff was considered in a further research project. Another project dealt with the leachate prognosis of biocides and their metabolites from building facades into the groundwater.

In another interesting project, surveys and a comparison of instruments for maintaining the intrinsic value of water supply and sewage disposal infrastructures were carried out, which then resulted in recommendations for action for the Bavarian water management administration.

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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 settlement 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.

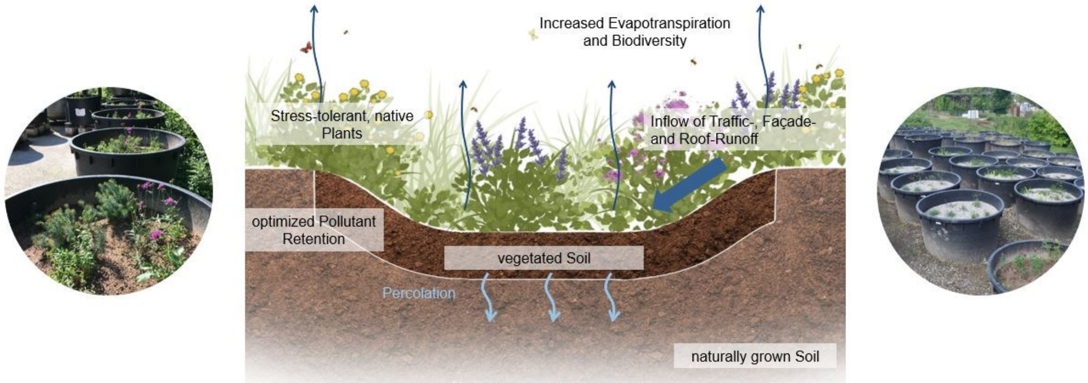

Figure 6: Schematic structure and effect of multifunctional infiltration swales.

The aim is 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 is carried out by employees of the HSWT. The Chair of Urban Water Systems Engineering (SWW) focuses on the development of a suitable and optimized vegetated topsoil by means of substrate amendment. In the first half of 2021, the laboratory experiments on the retention of pollutants through different substrates were mainly completed. In July 2021, semi-technical experiments were set up open air with vegetation at both the HSWT and the SWW to investigate the material load and operational stability (Figure 6). 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 spring 2022, piloting in a residential area is planned with the proven soil-substrate mixtures and different plants from the semi-technical experiments. Additional observation of stormwater tree pits with the topsoil-substrate mixtures were done.

This research project forms the basis for a future guideline for operators and planners, from which the ecological and economic advantages, as well as the effort for maintenance, will become apparent.

Funding:
Bavarian Environment Agency
Bavarian State Ministry of the Environment and Consumer Protection

Collaboration:
Weihenstephan-Triesdorf University of Applied Sciences, Soil-Institute
Johannes Prügl, Engineering Office for Soil and Vegetation Technology

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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

Accompanying Research "Climate-friendly Construction – Model Projects"

The consequences of anthropogenic climate change are also visible in Bavaria and, depending on the level of future global emissions, will have significant impacts in the coming decades. In the future, Bavaria will have to prepare for more frequent extreme weather events, such as intense and prolonged heat waves and dry phases, as well as longer-lasting rain events and heavy precipitation events. Accordingly, the urban environment, the construction and design of buildings and open spaces must already meet the changing external circumstances and rise to the challenges today.

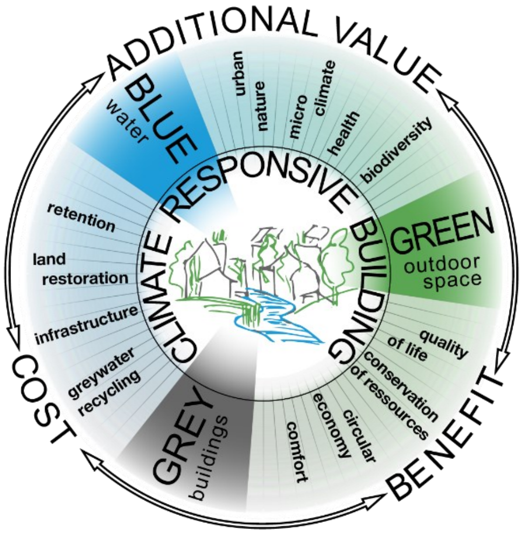

Figure 7: Aspects of climate-friendly construction.

An important component of climate-friendly building is on-site stormwater management. A water-sensitive settlement development aims to come as close as possible to the natural local water balance in order not to overload the municipal drainage systems, as they are not prepared for the impacts of climate change (e.g. flooding, combined sewer overflows during heavy rainfall).

Within the scope of the project, quantitative and qualitative aspects from a water management point of view are investigated for this purpose. For selected model projects, simulations of different climate scenarios (heavy rainfall to extreme dry periods) are carried out and used to evaluate the influence of blue-green measures on the adaptability to climate change.

The research project serves as scientific support for the implementation of ten model projects in Bavaria with regard to urban climate adaptation (adaptation) and climate protection (mitigation) in municipal housing construction. The aim is to demonstrate the feasibility of blue-green-grey climate adaptation measures in municipal housing, considering the long-term economic viability, which will have a positive impact in times of climate change and the associated increase in the number of extreme weather events.

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FUNDING:

BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

Surveys and Comparison of Instruments for Maintaining the Intrinsic Value of Infrastructures for Water Supply and Sewage Disposal

The proper water supply and sewage disposal are essential and indispensable compulsory tasks of the general interest of the municipalities. Reliable maintenance of these infrastructures is therefore imperative. For a sustainable maintenance strategy of the water supply and wastewater disposal infrastructure, suitable combinations of all technical and administrative measures as well as management measures must be considered and used during the life cycle. In the interests of equal living conditions, the promotion of drinking water and sewer networks must be also linked to concepts for dealing with demographic development.

Figure 8: Renewal of a section of the sewer.

The aim of a study commissioned by the Bavarian State Ministry of Environment and Consumer Protection was to develop a support for maintaining the substance value of the Bavarian drinking water supply and sewage disposal. For this purpose, an overview of instruments for rehabilitation planning and to support the maintenance of the intrinsic value of infrastructures as well as an overview of technical and financial support for maintaining the value of water infrastructures in Germany and other European countries has been compiled. The results were evaluated and recommendations for action on the use of instruments for maintaining the value of the value for the Bavarian water industry were derived.

The recommendations for action derived from this study provide the Bavarian water management administration with a wide range of instruments that can facilitate the maintenance of the water infrastructure.

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FUNDING:

CHINA SCHOLARSHIP COUNCIL

Interaction of Heavy Metals and Biocide/Herbicide from Stormwater Runoff of Buildings with Dissolved Organic Matter

Building surface is an important source of stormwater runoff contamination, especially aged metal roofs and piping materials, bitumen membranes under green roofs as well as newly painted façades. Released pollutants include heavy metals (Cu/Zn), biocides (BAC), and herbicides (MCPP). They posed risks to the environment due to their high concentrations. Therefore, high efficiency on-site treatment methods are now urgently needed to safeguard the ecosystem. The basis for developing such treatment facilities is an in-depth understanding of their interactions with dissolved organic matter (DOM), as this affects their migration in the environment.

In our study EEM-PARAFAC was used to evaluate the interactions between Cu, Zn, BAC, MCPP and DOM at different pH. Mechanisms involved in BAC/MCPP-DOM interaction were revealed by 2D-FTIR-COS.

Results showed that the applied DOM was composed of the two different fluorescent components C1 and C2. More interaction with C1 than with C2 was observed for both Cu/Zn and BAC/MCPP. Increasing the pH enhanced the interaction between Cu/Zn and DOM. Contrarily, interaction between BAC/MCPP and DOM was impaired by high pH conditions. FTIR coupled with 2D-COS analysis revealed that mechanisms involved in BAC/MCPP titration include hydrogen bonding, π-π interaction, and electrostatic effect. The order of mechanisms taking effect during interaction with DOM is affected by the molecular structure of BAC/MCPP.

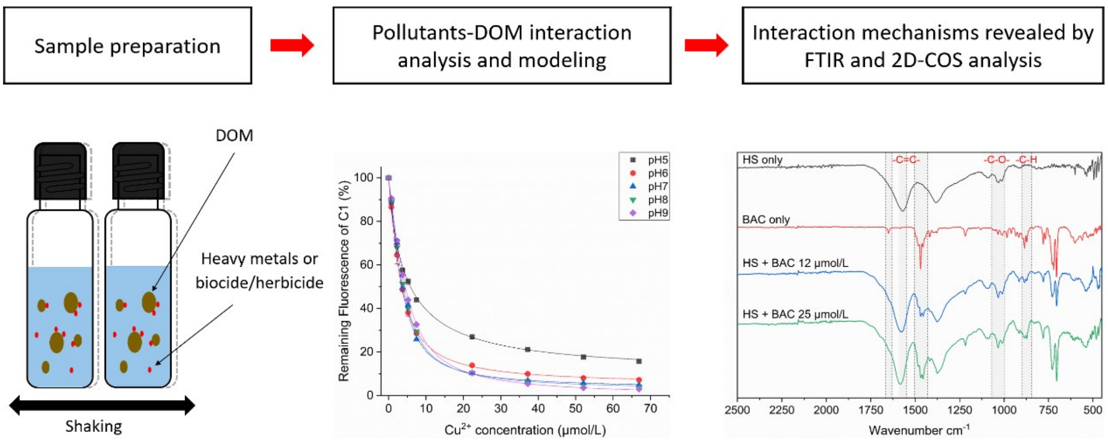

Figure 9: Graphical abstract of study on interactions between building surface originated pollutants and DOM.

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FUNDING:

ASSOCIATIONS FOR INSULATION SYSTEM, PLASTERS AND MORTARS GERMANY

COLLABORATION:

FRAUNHOFER INSTITUTE FOR BUILDING PHYSICS

Development of a Model to Assess the Environmental Properties of Common Outdoor Plasters and Mortars

Building products such as plasters and mortars are largely used on the outside of the buildings (e.g. mineral and organically bound plasters on masonry, thermal insulation composite systems, masonry mortars and other substrates). When these products are used outside, they are exposed to precipitation and ambient air. The leaking of rainwater dissolves the ingredients from the plasters and mortars and releases them. Since not every substance has an environmentally hazardous potential, the release of substances from construction products in contact with rainwater does not necessarily imply a negative impact on the environment. However, the evaluation of the leaching behavior of plasters and mortars in the case of a rainy façade is not yet possible, as there is no transfer model to conclude from the results of leaching tests on the actual deterioration of soil and groundwater.

The main objective of the project is to create a model that can describe the leaching mechanism of contaminants in a plaster and mortar facade during a random rainfall event. On this basis, an evaluation of the environmental characteristics should be carried out.

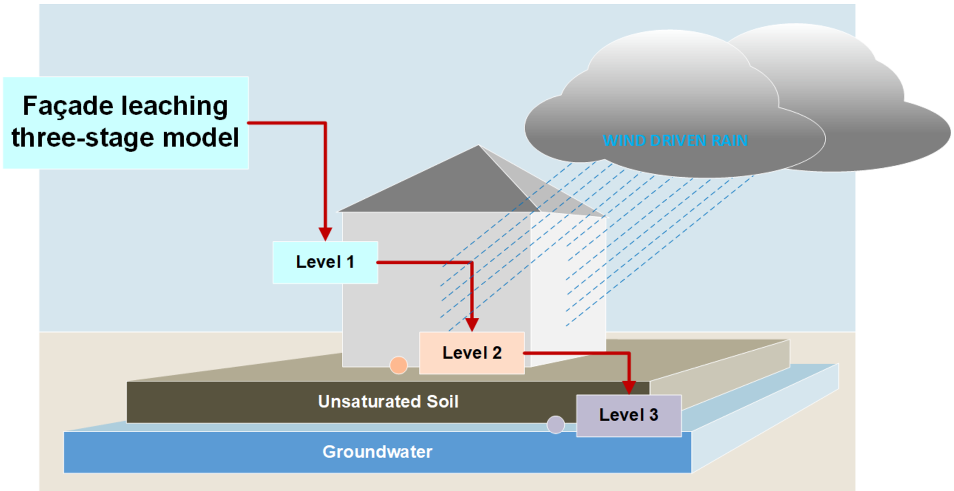

Figure 10: "3-Level Model" schema: The model is divided in three different levels; "Level 1" is the facade runoff model, "Level 2" is the model for leaching processes and substance transport on the facade and finally the "Level 3" is the leachate forecast and evaluation of the environmental impact.

To achieve this overall objective, three specific sub-objectives are planned.

1) Identification of the mechanisms underlying the leaching of ingredients from irrigated construction products.
2) Development of a model for the description of substances release (emission) from plasters and mortars.
3) With the use of the ground water risk assessment (GRA) a leachate forecast will be developed by modeling the material transport through "the unsaturated soil" up to a defined point of compliance and the comparison with limit values.

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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 treatment. While the treatment of wastewater, taking into account the specified limits, remains the top priority, the working group is looking for approaches to reduce the energy required for treatment while also to recover more energy from wastewater.

Over the last few years, we have been working on a project funded by the German Research Foundation (DFG) to investigate the influence of CO_2 enrichment during the fermentation of sewage sludge. Interestingly, it was shown that there was both an - admittedly - slight increase in methane productivity compared to the non-enriched control, but also that the resilience of the system to disturbances was improved (in this case, a continuous increase in the organic loading rate). These promising results should now be further investigated with energy crops and manure as substrate in another research project, which is thankfully funded by the Fachargentur nachwachsende Rohstoffe (FNR).

After delays caused by the pandemic, the pilot reactor for demonstrating microbiological methanation at the Garching wastewater treatment plant has now also been put into operation. With a trickle bed volume of over 1 m^3, it is the largest experimental plant of its kind in the world. We hope to be able to report on initial experiences and results soon!

In a large collaborative project funded by the German Academic Exchange Service (see: https://www.seed.tum.de/) with various chairs of the TUM and partner universities in the global south, we want to jointly develop approaches to realize sustainable energy supply from renewable sources in rural areas. In particular, we will focus on the identification of organic residue streams in order to generate biogas and, at the same time, a high-quality fertilizer for use in agriculture. Depending on the amount of biogas generated, this can be used either for cooking, for cooling or also for generating electricity.

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FUNDING:

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 materials and residues. Biogas production has a key role to play here because, unlike most other renewable forms of energy, it can be stored. Unfortunately, a not inconsiderable proportion of the methane potential still remains in the digestate. Studies have shown that, under certain conditions, enriching the anaerobic degradation process with CO_2 can contribute to an increase in methane productivity, while at the same time increasing the resilience of the process.

In this context, studies have shown that enrichment of the anaerobic degradation process with CO_2 can contribute to an increase in methane productivity under certain conditions.

The aim of the project is the energetic utilization of CO_2 to reduce the residual methane potential. In the process of biogas production, plant-based materials and in particular residual materials form plants are used whose behavior with CO_2 enrichment in anaerobic degradation has not yet been investigated. However, the use seems 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 main objectives of the study, the CO_2 uptake potential and the additional CH_4 production are to be quantified. By means of isotope analyses and microbiological investigations, the mechanisms and processes taking place are to be analyzed and better understood. The investigations will be carried out using continuously operated reactors.

Figure 11: Continuously operated biogas reactors.

The reactors are fed with different plant biomasses and in combination with manure. While one reactor is semi-continuously enriched with CO_2, the second serves as a reference under otherwise identical conditions. Finally, the knowledge gained about the process impact by CO_2 enrichment will be used to derive and present recommendations for the use of the effect for full-scale applications quantitatively in terms of CO_2 balance and economic efficiency.

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Design of Hybrid Nano-engineered Bioprocesses for Wastewater Treatment

The capability of microbes to reduce functionalized graphene compounds can be used for advanced biological treatment of wastewater. The addition of low-cost graphene oxide to an anaerobic community may enhance the redox conversion of persistent pollutants to their less toxic equivalents. The role of bio-reduced graphene oxide (bioRGO) in the anaerobic conversion of contaminants seems to be dual, as it may act as an electron shuttle between the microorganisms and the pollutants, and it may promote the direct interspecies electron transfer between the microorganisms.

This project focuses on developing a hybrid nano-engineered biotreatment based on bioRGO. We will evaluate the redox conversion and metabolic pathways of a range of pollutants persistent to aerobic treatment (e.g., halogenated, nitro and azo-compounds). The addition of graphene oxide will be evaluated under methanogenic and sulfate-reducing conditions. Given that the presence of bioRGO may also enhance methane production, the process will also be evaluated in terms of the production and quality of the biogas.

FUNDING:
EUROPEAN COMMISSION

COLLABORATION:
THE CATALAN INSTITUTE FOR WATER RESEARCH

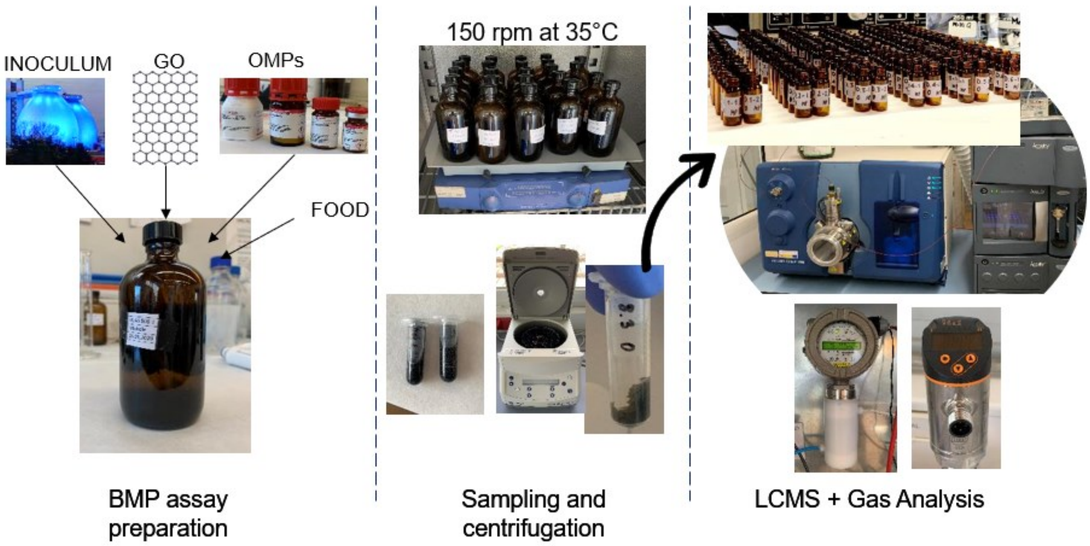

Figure 12: Experimental setup of batch assays experiment aimed at improved biogas production and micropollutant removal estimation.

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German Academic Exchange Service

Collaboration:

TUM SEED Center

Rural Biogas Generation

According to International Energy Agency (IEA) report, over 1.3 billion people all around the world still lack access to affordable and sustainable energy. Meanwhile, it was estimated that the energy demand will increase by 50 % within the next decades due to population growth. In the global south, this situation is even worse, and only 58 % of the urban population has access to energy. Furthermore, it was reported that over 600 million residents in the rural areas use charcoal and wood as dirty fuels for their daily energy production. Switching to the production of renewable and sustainable fuels, such as biogas from anaerobic digestion of organic wastes, would lead to a clear reduction in indoor air pollution and health improvements as well as time and costs savings in many cases. Biogas fuel benefits the entire community, as household heating and cooking are also significant sources of indoor air pollution.

On the one hand, addressing the challenges of providing access to affordable and sustainable energy are a highly complex and intertwined issue. On the other hand, the need for an improved efficiency give rise to off-grid implementation for affordable access and reduces carbon emissions. Therefore, this project aims to develop tailored and resilient treatment systems for rural communities in countries of the global south to convert biological waste streams generated, such as animal manure, crop residues, biowaste, and sewage sludge, into biogas for onsite use. This research is part of the TUM SEED Center and is going to establish several case studies demonstrating that even with relatively simple methods, a significant improvement of the living quality in rural areas can be achieved:

- Providing biogas as a renewable energy carrier for cooking, heating, chilling (of goods) and electricity generation,
- Mitigating deforestation and preventing indoor air pollution by replacing firewood by generated biogas including social benefits by rendering firewood collection unnecessary,
- Increasing the agricultural productivity by the application of organic fertilizers harvested from the biogas process,
- Reducing greenhouse gas emissions by a controlled release of methane from the organic waste streams in the digester.

Figure 13: SEED Center Website.

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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

The share of renewable energies in the German electricity mix is steadily increasing. An important 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.

A particularly promising concept is the microbiological production of methane in thermophilic anaerobic trickle bed reactors in which so-called archaea are immobilized on carrier materials. This microorganism use the supplied gases for their metabolism.

In a previous project, methanation in anaerobic thermophilic trickle bed reactors at lab-scale already demonstrated a high performance with methane production rates of up to 15.4 $L_{CH4}/(L_{trickle\ bed}*d)$ at methane concentrations in the product gas above 96 %. This would allow a direct injection of the biomethane into the natural gas network without the need for further gas purification.

In order to further test the potential of biological methanation in the thermophilic anaerobic trickle bed reactor, a pilot-scale reactor was installed at the Garching wastewater treatment plant.

With a reaction volume of 1 m^3, the applicability of the reactor concept should be demonstrated on a semi-industrial scale. This makes the reactor one of the largest anaerobic trickle bed reactors in the world.

The upgrading of biogas at the point of origin, the wastewater treatment plant, 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 gas supply of H_2 and biogas as an alternative CO_2 source is continuously increased. Currently, a methane production of 2.8 $L_{CH4}/(L_{trickle\ bed}*d)$ and a methane concentration in the product gas of over 98 % is already achieved. The gas supply is further increased while tightly monitoring the process stability.

Figure 14: Pilot-scale reactor at the Garching wastewater treatment plant.

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FUNDING:

GERMAN RESEARCH FOUNDATION

COLLABORATION:

HEIDELBERG UNIVERSITY, BAVARIAN STATE RESEARCH CENTER FOR AGRICULTURE

Increased Methane Productivity in Anaerobic Digesters by CO_2 Enrichment

Wastewater treatment plants use about 20 % of the municipal energy consumption and emit roughly 3 million tons of CO_2 every year. Thus, it is crucial to improve the balance between energy demand and energy production by additionally reducing the CO_2 footprint of wastewater treatment plants. Currently, the chemical energy bound in wastewater is, at least partly, recovered in form of energy-rich methane gas gained by the anaerobic digestion of sewage sludge. During the anaerobic treatment, CO_2 is produced as a byproduct.

Recent studies reported an increasing methane productivity by CO_2 enrichment. However, the transformation pathways that lead to an increased methane formation by CO_2 conversion have only been hypothesized so far. This project aims at identifying the main mechanisms of bioconversion of CO_2 by applying stable isotope labeling of the injected CO_2 and comprehensive microbial analysis of the digested sludge. Therefore, continuous anaerobic digestion tests are performed with two laboratory-scale biogas test systems.

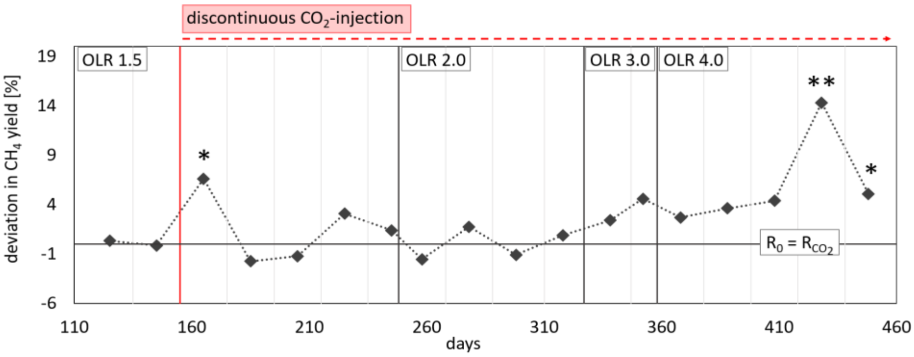

Figure 15: Average deviation of CH4 yield per hydraulic retention time at different organic loading rates (OLR) of the experimental reactor compared to the control.

Discontinuous CO_2-injection into the experimental reactor led to an initial increase of the methane yield compared to the control. However, a permanent increase in methane productivity was only achieved at high organic loading rates (OLR) and thus enhanced the availability of volatile fatty acids (VFA). This indicates that for an increased CO_2 to CH_4 bioconversion sufficiently high OLRs or substrates that lead to high VFA concentrations in the fermentation broth are needed.

The results will help to find the best full-scale operation conditions to increase the methane formation by CO_2 enrichment in the digesters. Using the "waste product" CO_2 in anaerobic digestion to exploit the potential for energy production from waste streams can therefore make a substantial contribution to advance the energy transition.

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Research Group Advanced Water Treatment

Despite the high treatment efficiency of conventional wastewater treatment plants (WWTPs), concern is raised regarding the removal of emerging contaminants including

- trace organic chemicals at ng/L to µg/L level (e.g. pharmaceuticals, per- and polyfluorinated alkyl substances)
- pathogens (bacteria, viruses, protozoa)
- antibiotic-resistant bacteria and resistance genes
- nutrients at low concentration (P, N)

Discharge from WWTP poses potential risk to aquatic ecosystems and human health. The work of this research group focuses on the evaluation and optimization of advanced water treatment processes and concepts for mitigation of these emerging contaminants. We apply advanced water treatment to mitigate discharge into the aquatic environment but also develop and assess concepts for (indirect) potable and non-potable reuse.

In one project, for example, we cooperate with the Münchner Stadtentwässerung to elucidate, if advanced treatment by ozonation can be optimized for an effective mitigation of trace organic chemicals and disinfection by pre-treatment with tertiary filtration. For this purpose, pilot-scale rapid sand filtration is tested on-site at the wastewater treatment plant and ozonation of secondary effluent as well as different filtrates was carried out with different ozone doses at bench-scale.

Figure 16: Bench-scale ozonation system.

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FUNDING:

FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COLLABORATION:

TEL AVIV UNIVERSITY

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.

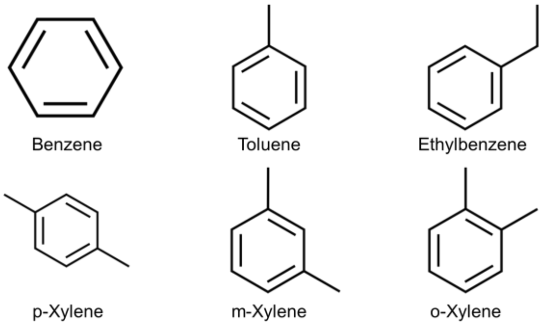

Figure 17: BTEX compounds.

Fundamental research on passive, bubble-free gas introduction at low flow velocities is first conducted in lab-scale reactors (Figure 18). 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.

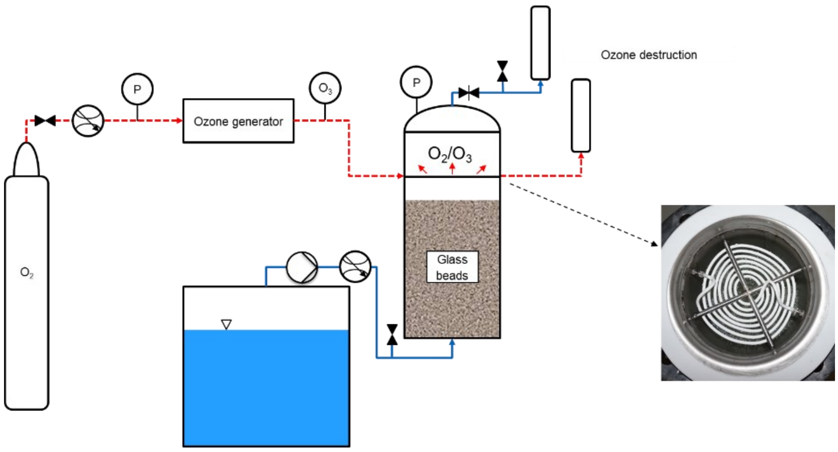

Figure 18: Experimental set-up to study in situ ozonation.

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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FUNDING:
GERMAN RESEARCH FOUNDATION

COLLABORATION:
HELMHOLTZ CENTER FOR ENVIRONMENTAL RESEARCH

Ozonation With Heavy Oxygen (^{18}O): A Novel Labelling Technique for the Elucidation of Ozonation Products

Chemical oxidation by ozone is an established technology for the efficient oxidation of contaminants of emerging concern (CECs) in water treatment. Despite its utility, it has one major disadvantage, the formation of stable and potentially toxic ozonation products (OPs). This drawback has garnered attention in the scientific community, due to the unknown and potentially detrimental effects of OPs in the environment and on human health. To date, 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.

In this project we have developed a new labelling technique which contributes to the generation of transferable knowledge regarding the reactivity of different functional groups towards ozone and their ozonation products. We proposed the use of heavy oxygen isotopes (^{18}O) to produce a heavy ozone molecules, which can react with CECs and label their OPs. A ratio of N_2/O_2 was established to characterize the expected ^{18}O purities in a close loop system (Figure 19.A) and experiments with $^{18}O_3$ were conducted using a tertiary amine (venlafaxine) with the aim to label its ozonation transformation product, N-oxide venlafaxine (Figure 19.B), which is formed exclusively by one oxygen transfer reactions.

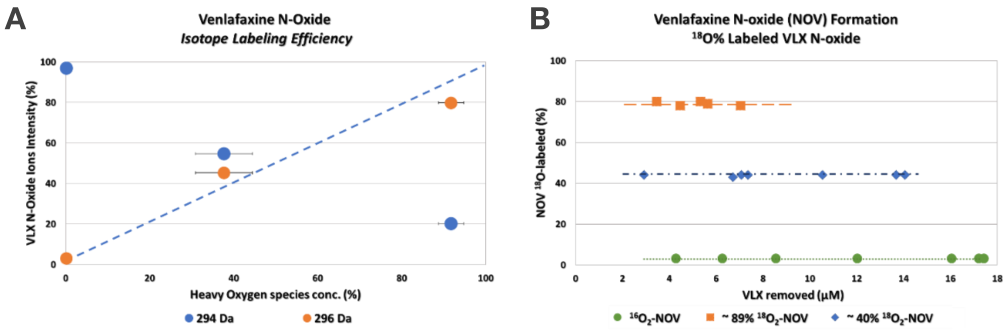

Figure 19: (A) The relative intensity of the ions of interest for the experiments with concentrations; ~99%$^{16}O_2$, ~34% $^{18}O_2$ and ~89%$^{18}O_2$. (B) Labelling of NOV depending on the $^{18}O_3$ /$^{16}O_3$ ratios applied in the ozonation experiments with dissolved $^{16}O_3$, ~89% $^{18}O_3$ and ~34% $^{18}O_3$.

With this novel approach, we are now able to determine OPs from oxygen transfer reactions of ozone with CECs as well as EfOM. It also facilitates the detection, identification, and elucidation of the generated OPs.

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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 will 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:

FUNDING:

EUROPEAN COMMISSION

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

COLLABORATION:

CATALYSIS RESEARCH CENTER AT TUM, FRIEDRICH-SCHILLER-UNIVERSITY JENA, UNIVERSITY OF SANTIAGO DE COMPOSTELA

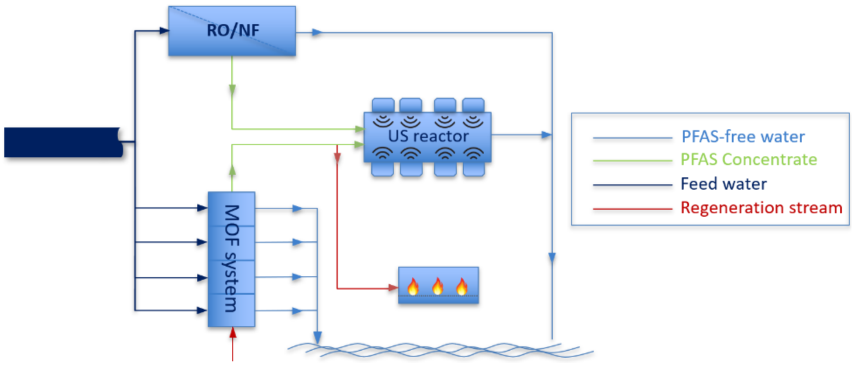

Figure 20: Schematic representation of the treatment concept for PFAS-polluted water.

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FUNDING:

EUROPEAN COMMISSION

COLLABORATION:

THE CATALAN INSTITUTE FOR WATER RESEARCH

Bioenergetic-metabolic Model for Prediction of Trace Organic Chemicals Bacterial Transformation

NOWELTIES is a Horizon 2020 Marie Sklodowska-Curie Innovative Training Network composed of 14 individual research projects. Common objective for all projects is to develop inventive water treatment technologies that allow catering for the varied treatment demands for a plethora of interconnected streams arising from recycling loops. Within this project we aim to model bacterial transformation of trace organic chemicals (TOrCs) by coupling co-metabolism and mixed-substrate growth in a bioenergetic-metabolic framework (Figure 21).

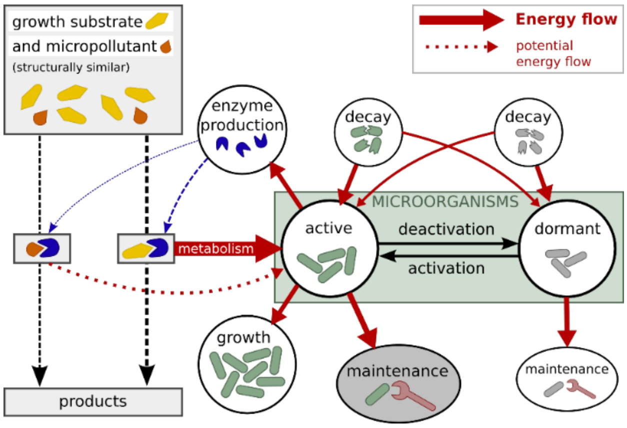

Figure 21: Illustration of the bioenergetic model developed at TUM and University of Tübingen.

As sand filter systems have shown good removal of TOrCs under oxic and oligotrophic conditions, a retentostat system (Figure 22) was set up to fundamentally study bacterial metabolism under oligotrophic conditions and to evaluate biotransformation of TOrCs by adapted bacterial communities.

Figure 22: Current experimental set-up able to run 10 experiments in parallel.

Aniline, histidine and di-sodium succinate were selected as major growth substrates for the adaptation of bacteria from activated sludge, because of their molecular similarities with some TOrCs.

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Research Group Water 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 recycling 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, the reuse of precipitation water or further treated (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 in 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 were able to start the new BMBF joint project 'Reclaimed Water' in 2021, which develops concepts for safe water reuse for urban and agricultural irrigation on a demonstration scale.

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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. It is representative for many regions in Germany, Europe and other locations that are facing a new water management situation and in which there is an urgent need to explore unconventional solutions. Building on the findings from a previous project, the next step in this project is the demonstration in order to investigate the possible implementation of water reclamation as a sustainable and innovative solution under the conditions of real laboratories with high transfer potential.

The project is part of the specific funding program of the Federal Ministry of Education and Research (BMBF) with the topic: "Water Technologies: Reuse". The aim is to develop new, highly flexible and needs-based management strategies for water reuse for urban and agricultural irrigation. The specific goals of the project are:

- Elaboration of the prerequisites for a legal implementation for urban and agricultural irrigation practices
- Establishing water quality requirements for different irrigation practices
- Development of contemporary digital approaches for the automated recording, archiving and determination of the irrigation requirement taking into account local and regional data in real time
- Implementation of innovative multi-barrier treatment technologies for the efficient reduction of microbiological and chemical contaminants
- Development of an automated, needs-based provision of advanced treated wastewater including automated systems for quality assurance, taking real-time data into account
- Development of innovative concepts for the implementation of reclaimed water water systems in existing infrastructure (e.g. irrigation systems)
- Conception of adapted operator models and possibilities of technology transfer
- Embedding the project from the start of the project in an interactive stakeholder process and
- Establishment of an innovative public relations platform to present concepts of reclaimed water use to an interested public

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

Funding:

Federal Ministry of Education and Research

Collaboration:

Brandt Gerdes Sitzmann Umwelt-planung GmbH, ALB Bayern e.V., COPLAN AG, Holinger AG, Rheinisch-Westfälisches Institut für Wasserforschung gemeinnützige GmbH, Leibniz-Rechenzentrum (other partners are listed on next page)

Provision of Reclaimed Water as an Alternative Water Resource for Non-potable Applications Using Hybrid Membrane-Ozonation System

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In water reuse applications, affected protected assets play an important role in risk management. These are including surface water, groundwater, soil, plants, and especially human health. To ensure a proper safety level concerning the unknown risks and uncertainties about the possible contamination exposure and their adverse impacts on human health, appropriate multiple barriers can contribute to a significant contaminant risk reduction. Thus, this research project will develop new, highly flexible, and needs-based system for water reuse for urban and agricultural irrigation purposes in a practical manner using a combination of advanced treatment technologies. These advanced processes include chemical oxidation (O_3), adsorption (activated carbon), ultrafiltration (UF) membrane systems, and UV irradiation. UF systems have been already applied in full-scale projects and provided promissing results regarding pathogens rejection when fed with treated wastewater effluents for reuse purposes. In previous studies it was demonstrated that the combination of ozonation and activated carbon filter could significantly enhance the removal of trace organic compounds (TOrCs). The interaction between these advanced water treatment processes will be studied during long-term operation of pilot-scale facilities at the WWTP Schweinfurt while focusing on a reliable and efficient removal of relevant pathogens, antibiotic resistance and TOrCs. Considering the removal efficiencies of different advanced treatment options, hybridization of these systems can provide a proper and reliable water quality for non-potable applications. By comparing the removal of TOrCs, relevant transformation products (TPs), pathogens, and mobile genetic elements (such as large plasmids or bacteriophages) during different treatment steps, the contribution of each process to the performance of the overall treatment train can be quantified.

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

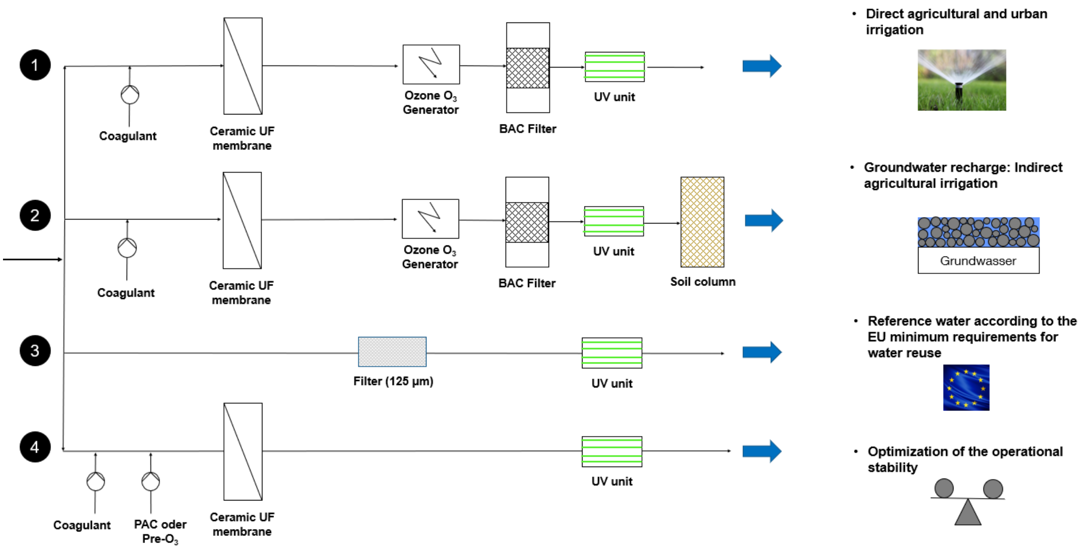

Figure 23: Multibarrier treatment system of Nutzwasser project for water reuse.

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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, 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.

Following the joint project, the goal is to further investigate and develop the *SMART* and *SMARTplus* technologies. With the *SMARTplus*-based plant at the TUM, it is possible to analyze the efficiency of inactivation of pathogens (especially viruses), the removal of antibiotic-resistant bacteria and genes and the reduction 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. With the help of intensified measurement data acquisition, the use of machine learning approaches for improved and automated control of the *SMARTplus* system in real-time should be investigated.

In addition, the application of the *SMART* concept at a demonstration-scale is planned and will be tested in collaboration with the Berliner Water Company (BWB). For this, the knowledge gained from the *SMARTplus* System (TUM) will be incorporated into the design and implementation of such a project.

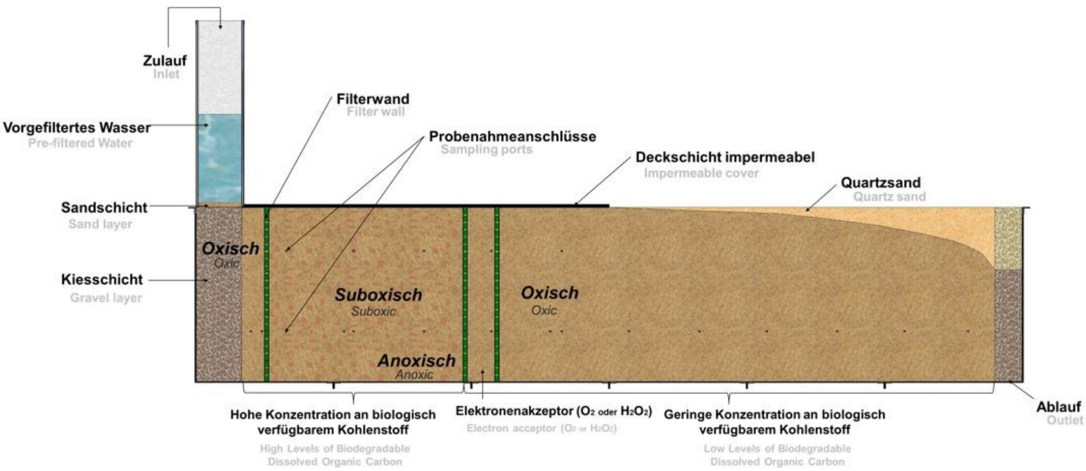

Figure 24: Schematic of the SMARTplus pilot-scale test facility at TUM (adapted from Karakurt-Fischer et al., 2020).

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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. 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.

Figure 25: WEF NEXUS approach.

Within the TUM Nexus Lab initiative (Nexus@TUM: www.nexus.wasser.tum.de) founded by Dr. Gondhalekar in 2021, the Urban WEF Nexus Research Group analyzes the interactions between the sectors water, energy and food, as well as other related sectors such as transportation and solid waste, and devises alternative future urban development scenarios to support the development of pilot projects at urban scales. The research group works in several case study locations including Germany, India, and Niger.

Figure 26: Series of international Urban Wef Nexus workshops.

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FUNDING:

FEDERAL MINISTRY OF EDUCATION AND RESEARCH

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

This project is part of a larger cooperation project funded by the German Federal Ministry for Education and Research (BMBF, 2020-2023) 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-design/-creation process of the pilot project together with the local community, thereby enabling co-ownership. In parallel, the project aims to conduct capacity building locally to anchor sustainable use of water as part of a climate change adaptation approach in the region.

Figure 27: Leh, Indian Himalaya

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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FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH

Nexus City: Enhancing Water, Energy and Food Security Through the Nexus Approach in Cities in India

Cities in developing and increasingly also in developed economies are already facing serious water-related development challenges. These are expected to intensify with climate change-related water uncertainty and scarcity, augmenting already existing and potential public health risk.

The WEF Nexus research group has been working in Leh Town, the capital of Ladakh, a semi-arid high-altitude region in the Indian Himalayas, for close to a decade. The project aim is to develop a WEF Nexus pilot project as a lighthouse project for water reclamation with integrated resource recovery in mountain regions in the region. Leh, with ca. 60,000 inhabitants and situated at the Indus River has expanded very rapidly in recent decades due to growth of the tourism industry. As a result, the town faces serious water-related development challenges. Currently, a centralized sewage system, which is very water and energy intensive, is being constructed. The project develops new knowledge about climate change mitigation and adaptation opportunities of the local water supply and wastewater management systems. Based on this, the project makes policy recommendations advocating decentralized urban water reclamation and reuse for water and energy conservation, as well as recovery of energy and nutrients, to support water, energy and food security as part of a climate change resilience strategy. This approach is being expanded by the Nexus group to other cities in India.

For more information on the WEF Nexus approach as it is being applied in the Urban WEF Nexus Research Group, please view the Nexus documentary film (2015): "If not now, when? Planning for the urban Water-Energy-Food Nexus" Duration: 18 minutes Link: https://vimeo.com/142941443

Figure 28: Leh, Indian Himalaya

The Nexus group works in Leh in close collaboration with His Holiness Chetsang Rinpoche, Venerable Sanghasena of Mahabodi Centre, the Ladakh Ecological Development Group (LEDeG), Bremen Overseas Development Cooperation (BORDA), Himalayan Institute of Alternatives (HIAL), Water Foundation, Water Solutions Lab of Future Earth, and others. This project has been funded by the European Commission and German Research Foundation (DFG) (2011-15), TUM Global Incentive Fund (2017-18), Bavarian State Ministry of Environment and Consumer Protection (2018-19), and German Federal Ministry for Education and Research (BMBF, 2018-2022).

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Research Group Membrane Filtration

Membrane processes play a central role in the closure of internal water cycles, 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, and the retention of microbial and chemical contaminants in high-pressure membranes.

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.

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FUNDING:

FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COLLABORATION:

UV-EL GMBH, DELTA UMWELT-TECHNIK GMBH

Development of a UV Irradiation System to Increase the Resource Efficiency of Water Treatment by Reverse Osmosis Membranes

As part of a collaborative BMBF research project, we aim to develop an innovative UV irradiation system that is based on pulsed UVC-LEDs to mitigate biofouling in reverse osmosis (RO) membrane processes by UV pre-treatment. UVC-LEDs have many advantages over conventional mercury vapor lamps, which makes them environmentally friendly and, due to their size, they can potentially be integrated into the pressure vessel of RO membrane systems as an in-situ treatment.

The membrane filtration research group investigates the efficiency of the novel UVC-LED system in lab- and pilot-scale experiments. Accelerated biofouling experiments are conducted by additionally dosing nutrients to the feed water. A pre-defined biofouling protocol allows conducting biofouling experiments with and without UV pre-treatment in a well-defined and reproducible manner.

The UVC-LED system will be characterized with regard to its UV fluence by using actinometry and biodosimetry. A further research focus of this collaborative project is to evaluate the efficiency of the innovative UVC-LED system on the basis of typical membrane module performance parameters, such as permeability decline and feed channel pressure drop (FCPD) increase (Figure 29). The built biofilms are extracted and analyzed for various parameters including ATP content, extracellular polymeric substance composition and microbial diversity. Further the removal of the formed biofilms is investigated.

When applying an intermittent current as power supply, UVC-LEDs can generate pulsed irradiation. Through fundamental investigations, we plan to determine the inactivation efficiency and mitigating effects on biofouling of pulsed UVC irradiation at various duty cycles and fluence rates.

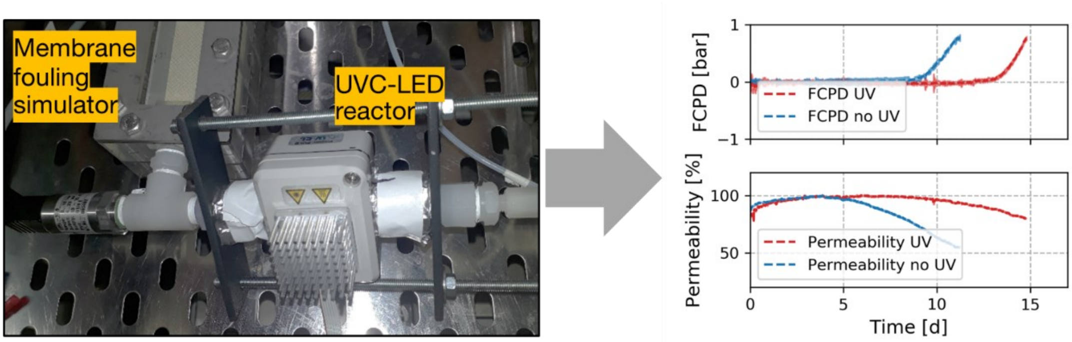

Figure 29: UVC-LED reactor attached to a membrane fouling simulator and the effects of UV pre-treatment on the feed channel pressure drop (FCPD) increase and permeability decline (Sperle et al.,Membranes 2020, 10, 415).

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FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH

Optimizing the removal efficiency of antibiotic-resistant bacteria and antibiotic resistance genes by microfiltration and ultrafiltration in municipal wastewater treatment plants.

Antibiotic resistance is not only a threat to human health in clinical settings, but also a challenge to the environment in terms of the spread of antibiotic-resistant bacteria (ARB) and antibiotic resistance genes (ARG) in aquatic environments. Antibiotics are used to treat bacterial infections in human and veterinary medicine worldwide. In aquaculture, antibiotics are used as growth promoters. Since humans and animals cannot completely metabolize antibiotics, large quantities of antibiotics and antibiotic-resistant bacteria enter the so-called urban water cycle (wastewater, sewage sludge, slurry, surface water, drinking water) via excreta.

The spread of antibiotic resistance was studied in the BMBF HyReKa research project from 2016 to 2019. The aim of the project was to analyze antimicrobial-resistant bacterial pathogens in clinical, agricultural and municipal wastewater and to assess their biological or hygienic-medical relevance and significance for drinking water in raw water.

Conventional wastewater treatment plants reduce ARB and ARG by 2 to 3 log levels. When surface waters are used as bathing water or drinking water or for irrigation in agriculture, the treatment capacity of a conventional wastewater treatment plant is not sufficient.

The aim of the project in wastewater treatment was to investigate more advanced treatment processes of ozonation, UV irradiation and membrane filtration to reduce ARB and ARG.

The most efficient technology for ARB and ARG reduction was membrane filtration. Further experiments with membrane filtration included studies of the removal efficiency of ARB and ARG after water backwashing and after chemical backwashing. In addition, recontamination and antibiotic resistance development in the filtrate of membrane filtration were investigated.

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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. We are looking for ways to better understand microbial functions. One focus of research is the interaction and diversity of organisms within microbial biofilms with a focus on fungi and their function.

Microbes possess a number of enzymes for the degradation of all kinds of substances, ranging from high molecular weight polymers to aromatic compounds. Fungi are a group of microorganisms that produce very efficient exoenzymes that can transform difficult-to-degrade organic substances. Of particular interest are the largely unexplored aquatic fungi that could potentially be used in wastewater reactors. 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. Molecular methods are often used quantitatively (qPCR) or qualitatively (high throughput sequencing, microscopy, flow cytometry). A new BMBF-funded project is examining the potential of biomarkers in wastewater exemplified with the SARS-CoV-2 virus abundance in municipal wastewater streams.

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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

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 30). 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.

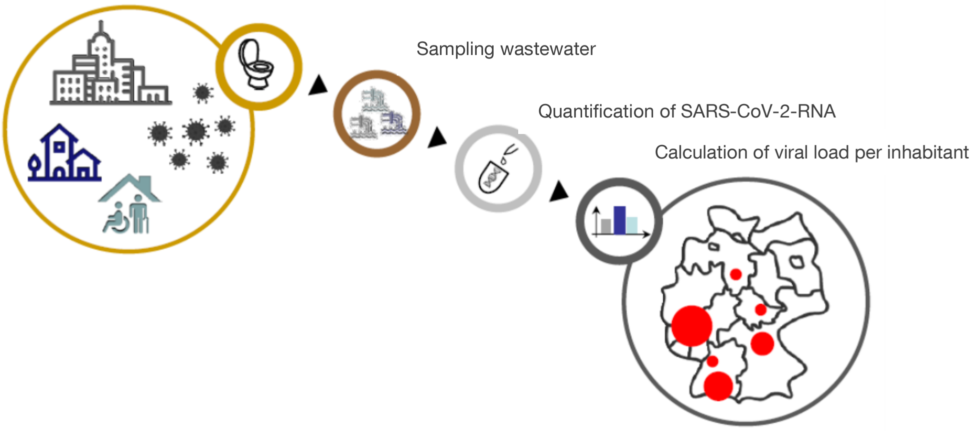

Figure 30: Concept of wastewater monitoring of SARS-CoV-2. Image: Claudia Stange, Johannes Ho. Kollaboration with TZW Karlsruhe. Funded by BMBF.

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FUNDING:
CHINA SCHOLARSHIP COUNCIL

COLLABORATION:
STOCKHOLM UNIVERSITY

Removal of Trace Organic Compounds by Functional Microbial Model Communities

Trace organic compounds (TOrCs) such as pharmaceuticals, personal care products, pesticides, has become emerging concerns in aquatic environment. These anthropogenic and xenobiotic compounds are frequently detected in surface water, ground water and even drinking water at the concentration ranging from few ng·L^{-1} to several µg·L^{-1}. Biological treatment is a promising technology as microbial communities bear a high potential to eliminate TOrCs via enzymatic degradation processes. However, the complexity of microbial interactions based on numerous species in realistic environment impedes the exploration of TOrCs biotransformation mechanisms, making it remain elusive to date. The aim of this study is to uncover the TOrCs biotransformation "black box" by simplified "model communities". Model communities with reduced complexity, either due to low species richness or dominance by one or a few populations, have been commonly used to overcome the challenge. A model community is defined as a closed assembly of microorganisms that represents or mimics the systemic behavior of ecological communities under controlled conditions.

Model communities were derived from natural environment including sediment core (Osterseen, Bavaria), activated sludge (WWTP, Garching), technical sand (lab-scale biofiltration column, Garching), tap water (Garching) and soil (Garching). We used dilution-to-extinction method to cultivate model communities in 96 deep well plates. Communities which can grow up successfully and efficiently degrade a mixture of 27 TOrCs were selected as model communities. The effect of TOrCs concentration, initial cell counts and medium type on the communities growth and degradation performance was investigated. The taxonomy composition of model communities were characterized. The link between TOrCs biotransformation and species interactions will be studied in the future.

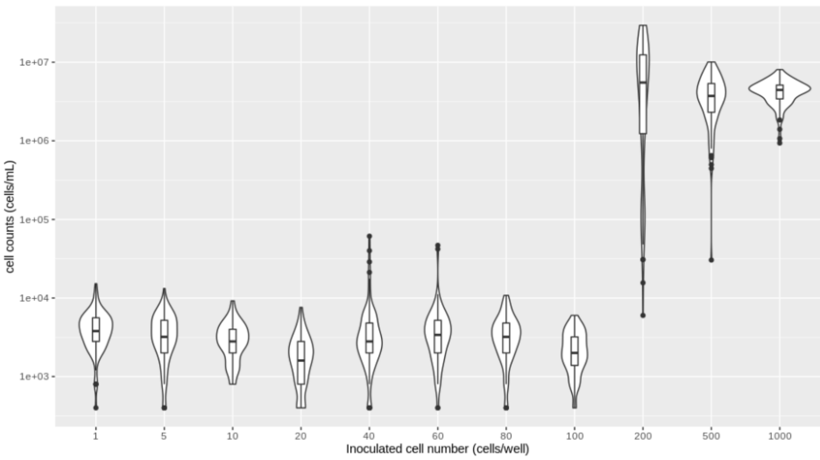

Figure 31: The effect of inoculated cell number on the growth of model communities.

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FUNDING:

GERMAN SCIENCE FOUNDATION

COLLABORATION:

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Resolving Aquatic Fungal Dark Matter (FDM) Using Laser Dissection and Long-Read Sequencing

Fungi play key roles in organic matter degradation and nutrient cycling, and their diversity is estimated between 2.2 and 3.8 million species. However, much of this is still unknown so far with only ~149 000 formally described fungal species. This disparity between known and unknown fungi is even more pronounced in aquatic habitats. Mycologists have applied culture-independent next-generation sequencing technologies to bridge this gap between known and unknown fungi. Nevertheless, these efforts turned out to be not enough to populate the Fungal Tree of Life (FToL) with newly described fungal species.

Therefore, being part of the Microbial System Research Group, I am working towards establishing a workflow that combines laser microdissection of single cells with whole genome amplification and long-read sequencing. We have tested different aquatic habitats for hunting of specific fungal groups with success, e.g., aquatic hyphomycetes (known for leaf litter degradation) and chytrids (parasitic fungi).

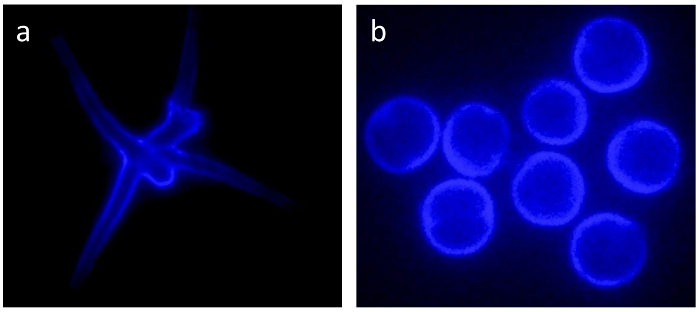


Figure 32: a) Aquatic hyphomycetes spore collected from community sample, b) unknown microbial cells collected from pond samples stained with Calcofluor-White.

Moreover, we are also investigating the interactions of different fungal groups with other eukaryotes in a salinity gradient in the Baltic-sea. Here we are analyzing microbial community sequenced data to elucidate the effects of salinity gradient on prokaryotes and eukaryotes communities including fungi using microbial network analysis approach.

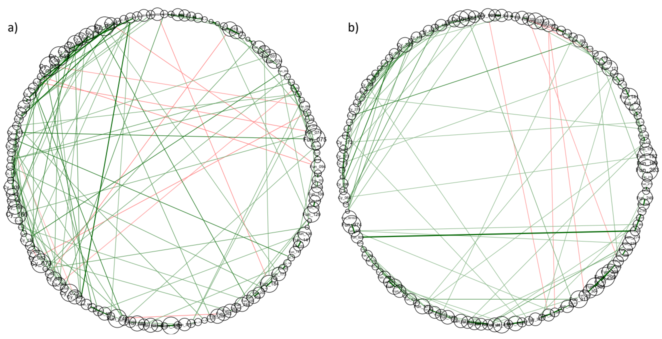
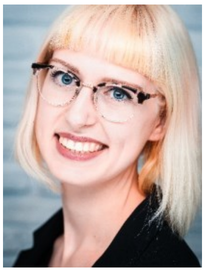


Figure 33: Microbial interaction network of fungi with autotrophs in a) high salinity and b) in low salinity environments.



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Function of Aquatic Fungi in Biofilms of Water Treatment Systems

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 with the whole microbial community. The superordinate objective of this study is to gain insight in the function and diversity of fungi in wastewater treatment plants (WWTPs). Besides using biofilms in down-flow hanging sponge (DHS) reactors fed with wastewater as model systems, screening of WWTPs is carried out. Since biofilms are promising habitats to study fungi, qPCR and ribosomal marker genes are used to investigate the composition. The interaction network between present microorganisms in the system and the functional role of fungi are going to be studied. Lastly the identification of basic active enzymatic pathways of fungi in the community is intended.

FUNDING:
GERMAN RESEARCH FOUNDATION

COLLABORATION:
BAVARIAN STATE RESEARCH CENTER FOR AGRICULTURE

To enable those examinations the development and optimization of standardized and reliable workflows for (meta-)barcoding, stable isotope labelling and metatranscriptomics of Cryptomycota are pursued.

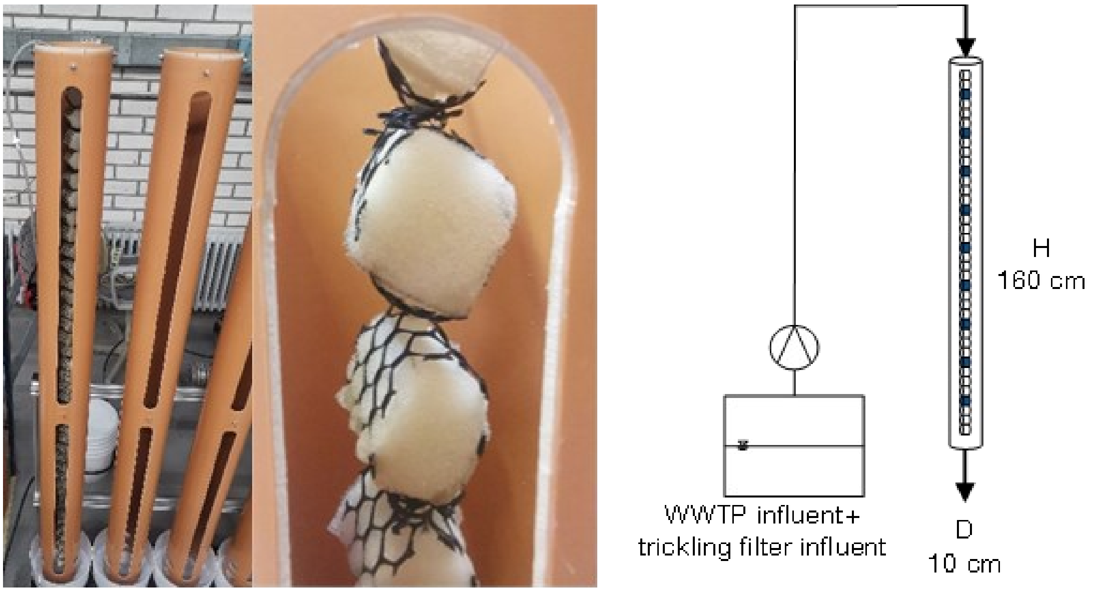

Figure 34: DHS reactor with polyurethane sponge filling material.

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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

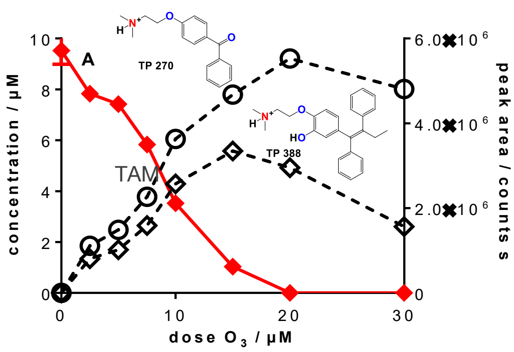

Figure 35: Left: AB Sciex QTRAP 5500 mass spectrometer for the identification of transformation products. Right: Example for the formation of transformation products during ozonation.

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FUNDING:

BAVARIAN RESEARCH FOUNDATION

COLLABORATION:

INSTITUTE FOR ENERGY AND ENVIRONMENTAL TECHNOLOGY E.V.

Sample Preparation Methods for Micro- & Submicroplastics in Environmental Matrices: Validation and Field Study

There is an urgent need to reliably quantify and qualify microplastics in the various environmental matrices. However, such a task involves distinguishing microplastic particles from natural particles such as sand, plant and animal debris. Even with the employment of spectroscopic identification methods like Fourier-Transformation Infrared spectroscopy (FTIR) and Raman spectroscopy, the interference caused by the natural particles can significantly impede the detection of microplastics. Hence, microplastics need to be separated from their natural matrices. Organics have a similar density to microplastics and need to be removed via chemical digestion methods, such as oxidation, alkali, acids, and enzymatic reactions. These reactions may inadvertently alter the microplastics being investigated.

The goal of this study was to optimize and validate a standardized sample preparation method to remove organic matter from wastewater samples, without altering the microplastics. This was tested on several microplastics (PS, PE, PP, PET, PVC, PA and PLA) by first optimizing and validating the sample preparation methods for larger microplastics fragments (80 – 330 µm) and then re-validating the two resulting methods (Hydrogen peroxide and Fenton protocols) for smaller microplastic fragments (< 10 µm).

Fenton reaction was further utilized during a field sampling campaign in cooperation with “Das Institut für Energie- und Umwelttechnik” (IUTA), where effluents of Wastewater treatment plants (WWTPs) were sampled to determine the microplastic retention efficiency of a tertiary sand filter. The sampling system consisted of a sealed system made entirely out of metal to avoid plastic contamination. The system consisted of a high-volume pump and three modular cartridges, where a set of steel mesh candle filters (100 µm, 50 µm, 10 µm) were placed in a cascade. Additionally, the effluent of the 10 µm filter was also sampled in order to account for smaller particles (< 10 µm). Sampled volumes were 5000 - 7000 Liters for 100 µm & 50 µm filters, 200 Liters for 10 µm filter, as well as 2.5 Liters for the fraction < 10 µm.

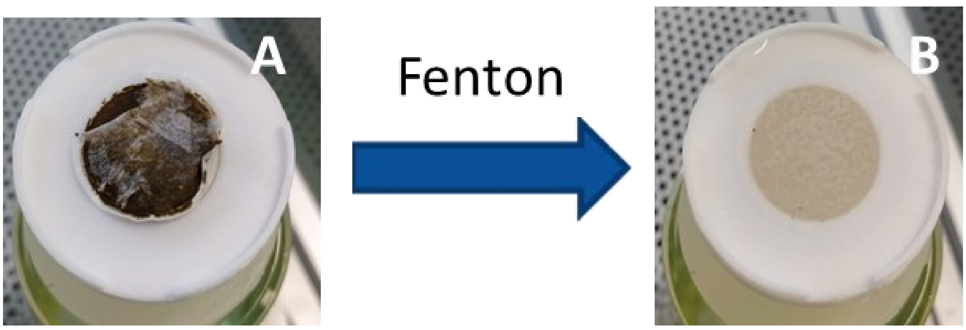

Figure 36: Effect of sample preparation: A. Filtered sludge sample, B. After Fenton treatment.

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FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COLLABORATION:
BS-PARTIKEL GMBH

Analysis of (Sub)Microplastic Particles and Sorbed Trace Organic Chemicals with TD-Pyr-GC/MS

The focus of this work within the interdisciplinary research project "SubμTrack" is on the analysis of "submicroparticles" (50 nm -100 μm) and adsorbed pollutants, such as pesticides or insecticides.

Micro-, submicro- and nanoparticles are increasingly regarded as vectors for trace organic chemicals (TOrCs). In order to determine adsorbed trace organic chemicals on polymers, a complex sample preparation has usually had to be carried out. Using a newly developed method of thermodesorption-pyrolysis-gas chromatography-mass spectrometry (TD-Pyr-GC/MS) it is possible to identify adsorbed TOrCs on the particles as well as the polymers in one analytical set-up. This ensures a high sample throughput for the qualitative analysis of trace substances and polymers, as the measuring time per sample is only 2 h. First, the adsorbed substances are desorbed from the particle by thermal desorption (TD); then the polymer is fragmented by pyrolysis (PYR). Both techniques are directly coupled to the same GC-MS system that analyzes the desorbed molecules or pyrolysis products, as shown in Figure 37.

Within the scope of this method development, the trace substances phenanthrene, triclosan and α-cypermethrin were tested on the polymers polystyrene (PS), polymethyl methacrylate (PMMA) and polyethylene (PE). Defined and additive-free particle sizes were used, including polystyrene (sub)micro (41 μm and 40 μm) and nanoparticles (78 nm) as well as PE and PMMA particles in a size of 48 μm. It could be shown that the sorption of phenanthrene (PMMA 48 μm << PS 40 μm < PS 41 μm < PE 48 μm < PS 78 nm) and α-cypermethrin (PS 41 μm < PS 40 μm < PE 48 μm < PMMA 48 μm < PS 78 nm) is strongly polymer-dependent. Triclosan adsorbed only on PE and on the PS nanoparticles (78 nm).

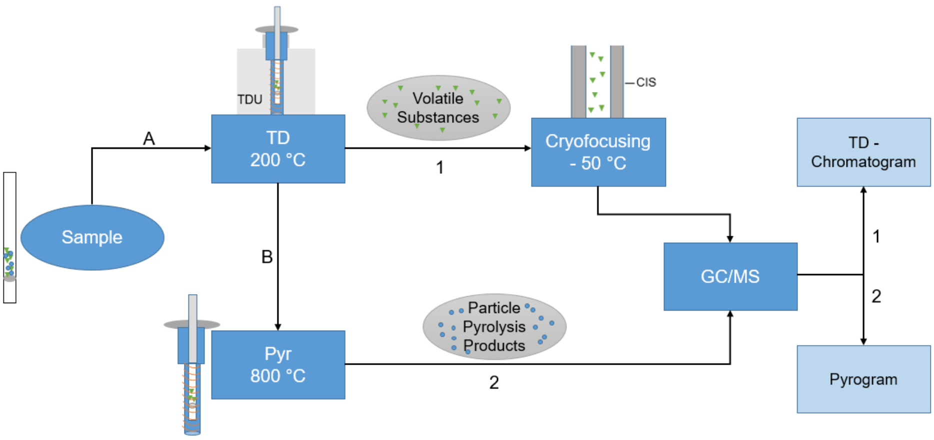

Figure 37: Flowchart TD-Pyr-GC/MS: (A) Thermodesorption of the sample (200 °C), whereby the volatile substances are desorbed (1) and cryofocused in the cold injection system (CIS, followed by a GC/MS analysis. The same sample (B) is then pyrolyzed at 800 °C (2) and introduced into the GC/MS.

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Advanced Wastewater Treatment in Weißenburg, Experiences from Full-Scale Operation

The installation of additional treatment barriers in municipal wastewater treatment plants is considered a viable option to mitigate the discharge of anthropogenic trace organic compounds (TOrCs) into receiving streams. In a Bavarian pilot project the wastewater treatment plant of the city of Weißenburg was equipped with an advanced treatment unit in 2017. Here, advanced treatment consists of ozonation with subsequent filtration over sand or granular activated carbon.

Key aspects of this project which started in January 2020 are the examination of TOrC removal achieved by the advanced treatment unit in Weißenburg during regular operation, a process evaluation and the development of recommendations for the future operation of the unit. The plant operation is evaluated via sampling campaigns and the analysis of an extended list of indicator substances and other relevant process parameters. Besides monitoring the removal capacity of the unit, also the potential for operational and economical optimization is investigated. Here, especially the optimization of the ozonation process control via the ΔUV_{254} concept is a focus of this study. To evaluate economical aspects related to the advanced treatment, costs for maintenance and operation during regular operation are analyzed. Besides, the study assesses common process options for advanced treatment for their synergistic potential

(e. g. additional removal of nutrients and COD, and improvement of the microbial water quality).

Based on the results from this study, recommendations for the design and operation of advanced treatment units at Bavarian wastewater treatment plants for the enhanced removal of TOrCs are to be derived.

FUNDING:
BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

COLLABORATION:
STADTENTWÄSSERUNG WEIßENBURG, WEBER-INGENIEURE GMBH, INGENIEURBÜRO DR. RESCH + PARTNER PARTG

Figure 38: Advanced treatment unit at the wastewater treatment plant Weißenburg.

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COLLABORATION:
AFIN-TS GMBH,
WESTFÄLISCHE WASSER- UND UMWELTANALYTIK GMBH,
NORMAN NETWORK

External Doctoral Candidates

Comparing Samples Treated with Activated Carbon by Their Fingerprints of Highly Polar Molecular Features

Surface water samples were treated in batches with different types and different amounts of activated carbon. Beforehand, the samples were spiked with a multicomponent standard mixture. Prior to the analysis, the samples were filtered and spiked again with internal standards. They were then measured using polarity-extended chromatography, consisting of hydrophilic interaction liquid chromatography (HILIC) and reversed-phase liquid chromatography (RPLC) coupled to a high-resolution mass spectrometer.

Following the "non-target screening" approach, full scan data of a broad mass range was acquired.

Molecular features are now extracted from the data, specified by their mass, retention time and signal intensity. The features from the sample treated with activated carbon are compared with those from the untreated sample and the changes in signal intensities are expressed by the fold changes. It is assumed that a logarithmic fold change of 0 indicates consistency.

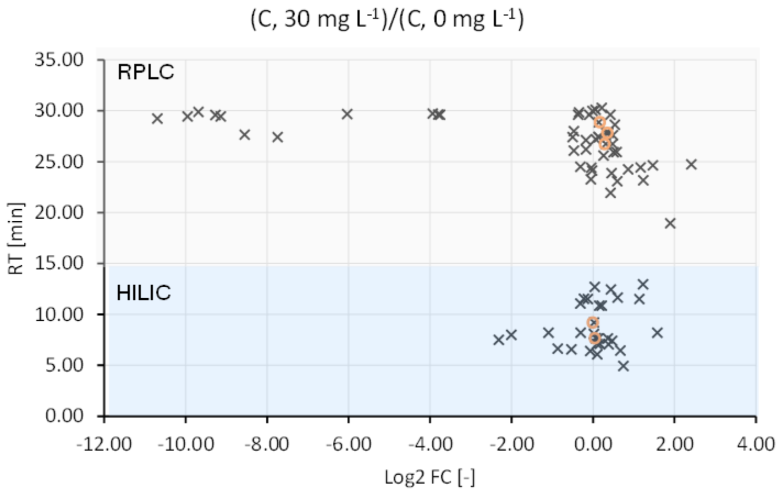

Figure 39: Logarithmic fold changes (FC) are plotted against the chromatographic retention time (RT). Polar features eluted before 15 min from the HILIC column (blue). Internal standards are marked by the orange circles.

Susanne Minkus is an external PhD student and employed by the AFIN-TS GmbH in Augsburg. She is supervised by Prof. Dr. J. Drewes and Dr. PD T. Letzel.

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Funding:
Bavarian Environment Agency

Screening for Unknown PFASs in a Polluted Surface Water

Due to chemical policy restrictions for longchain perfluorinated substances an increasing number of per- and polyfluorinated substitutes are used in industrial and consumer products. Often nether the chemical structure nor analytical standards and methods are available allowing to analyze these substances.

The Non-Target- and Suspect-Screening-Analysis are used for the identification of unknown or suspected substances in water samples. From January 2020 to July 2021 a monthly Non-Target Screening for unknown and suspected PFAS in river water samples taken up- and downstream from an industrial PFAS-discharge was carried out. The exact mass of the molecules in the samples can be determined with high resolution and accurate LC-MS/MS. The developed workflow enables the data reduction and prioritization on PFASs by e.g. mass defect and Kendrick mass defect plots. In addition to suspect lists, a fragment list was implemented to screen for characteristic neutral losses and fragment masses and facilitate the tentative identification of prioritized signals.

In downstream samples, expected perfluorinated carboxylic acids (PFCA) and the known PFOA-substitutes ADONA and GenX were detected with the Non-Target workflow. Furthermore, homologue series of partially fluorinated PFCA and further PFAS were tentatively identified. Insights from this Non-Target approach on novel PFAS can be used to optimize future wastewater monitoring programs.

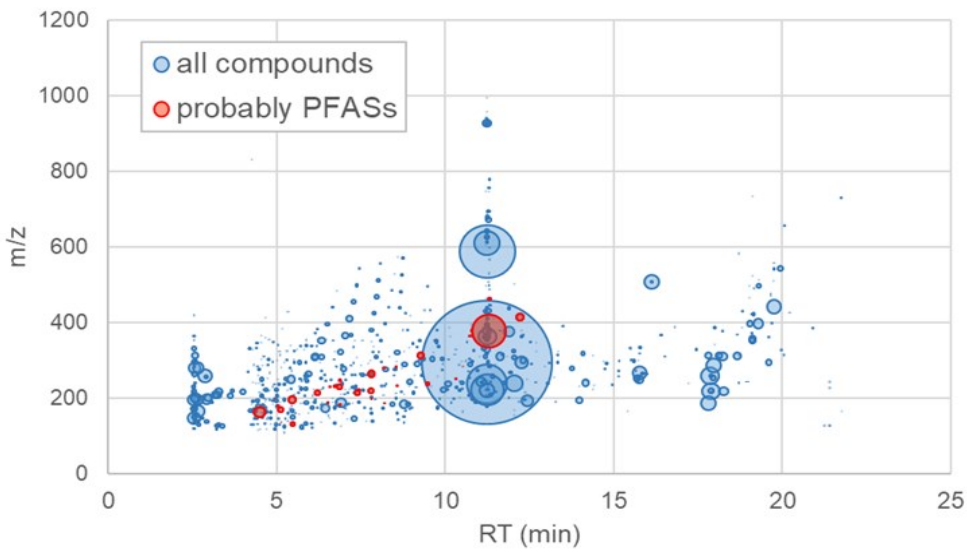
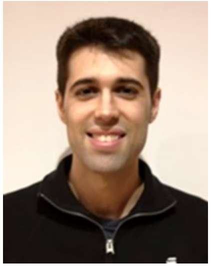


Figure 40: Compounds detected in the downstream river water sample by HR LC-MS/MS and reduction to probably fluorinated substances. The size of the dots corresponds to the peak area of the signal.

Hanna Ulrich is 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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Sergi Vinardell is a chemical engineer with special interest in environmental engineering and wastewater treatment. He is currently a PhD candidate at the University of Barcelona (Spain) and his research focuses on evaluating the technical and economic implications to implement anaerobic membrane bioreactors (AnMBR) as mainstream technology in wastewater treatment plants. During his PhD, he has been involved in European and national projects and he has collaborated in many investigations related to anaerobic digestion and membrane recovery processes. His research work has resulted in the publication of many articles in top-tier journals in his field.

Sergi Vinardell has conducted two research stays in prestigious European universities during his PhD. Specifically, he conducted a 6-months stay at the University of Montpellier (France) and 1-month stay at our chair from October to November 2021.

ANWAR DAWAS

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Dr. Anwar Dawas is a Postdoctoral Researcher from Tel Aviv University, Faculty of Mechanical Engineering, The Porter school of the Environmental and Earth Sciences, Israel. She is holding a PhD in Environmental Engineering from Technion, Haifa, where she worked on the “Integration of anammox and nitrifying bacteria in engineered systems for energy-efficient ammonium removal”. Her current research at the Zucker lab is focused on advanced oxidation processes for removal of contaminants in water.

Anwar’s postdoc research project is part of a joint project between Tel-Aviv University and our chair dealing with in-situ chemical oxidation with ozone (ISCO3) for the removal of contaminants in groundwater. The objective of the proposed research is to develop, test, and optimize a novel in-situ ozone-based oxidation process for the effective removal of BTEX from water. Core elements of the new concept is the passive injection of gaseous ozone by diffusion through gas-permeable membranes, and operation in sequential barriers to maximize decontamination. The distribution of ozone over multiple injection points along the membrane surface facilitates spatial distribution in the aquifer and thereby helps to overcome limitations of current point source injection systems.

Anwar visited TUM in November 2021 for one month through the BMBF funded “Young Scientists Exchange Program”, which is part of the German-Israeli Water Technology Cooperation. During her stay, she investigated the effect of contaminant (BTEX) concentration and radical scavenging capacity on their removal by ozonation and ozone-based advanced oxidation.

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Photocatalytic Recycled Membranes from TiO_2 and Graphene Wastewater

Emerging Contaminants (ECs) have attracted the scientific community's attention in recent years because they have already been detected in wastewater, surface, underground, and even drinking water. Although their effects are not fully understood, studies point to their potential toxicological risks. Conventional wastewater treatment plants and water treatment plants are inefficient in totally removing ECs, requiring advanced treatments for this purpose. That said, this project aims to develop and investigate a photocatalytic membrane reactor composed of the union of catalysts to membranes that generate synergic benefits. The immobilization of the catalyst on membrane surfaces is a promising alternative for its recovery and retaining in the reaction medium. The association also allows the reduction of membranes fouling through the degradation of the foulants compounds by the catalyst, keeping stable permeate flow and minimizing energy consumption.

One of the novelties of this project is to develop and evaluate the performance of Photocatalytic Membranes (PM) composed of recycled membranes (RO membrane after lifespan converted into UF/MF membrane), TiO_2 nanoparticles synthesized by greener route, and graphene oxide (GO). For this purpose, five steps are addressed. The first consists of synthesizing and characterization the PM and preliminary removal/degradation tests of dyes and synthetic matrix of Pharmaceutical Active Compounds (PhACs). The second step concerns the evaluation of the membrane's capacity to remove ECs from municipal wastewater after secondary treatment. In the third, the performance of the system with the catalyst immobilized and suspended will be evaluated. Fourth, the operating parameters will be optimized, and, finally, an economic analysis of Capex and Opex of the process will be carried out.

Preliminary results showed an increase in the membranes' performance modified with nanocomposites (dye removal ~100 % and almost constant flux) compared to ones without modification (dye removal ~ 56 % and flux drop approximately 32 %). In addition, the modified membrane was able to remove more than 90 % of some PhACs during UV-C irradiation for one and a half-hour of permeation.

Caique Oliveira is an external Ph.D. student from Federal University of Minas Gerais (Brazil) and his doctoral thesis is supervised by Prof. Dr. Jörg E. Drewes at TUM and Prof. Dr. Míriam Amaral.

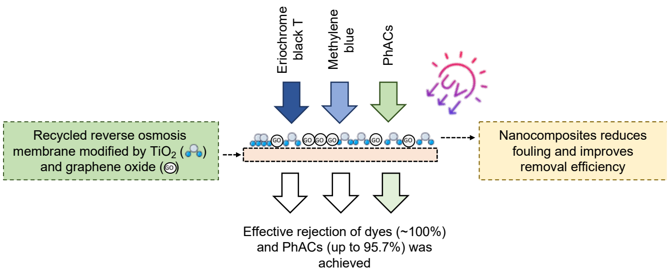

Figure 41: Principle of photocatalytic membranes.

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Synthesis, Characterization and Application of Functional Materials for Remediation of Emerging Contaminants in Water

In summary, functional materials ($CeWO_4$/waste plastics solar catalysts and MgO/nanocrystalline cellulose/SBA-16 mesoporous silica composite) were synthesized for mitigating environmental microplastics and antibiotics/antiviral drugs in contaminated water.

During the tree-month stay, not only synthesis, characterization and applications preparation of $CeWO_4$/waste plastics solar catalysts and MgO/nanocrystalline cellulose/SBA-16 mesoporous silica composite have been done but also the preparation of three manuscripts, which were submitted to international per-reviewed journals.

Two review manuscripts and one research paper on;

a) Global distribution, effects, and analytical techniques for environmental microplastics
b) Environmental Microplastics– Overview on the conventional & advanced oxidation processes for their removal
c) Surface equilibrium and dynamics for the adsorption of anionic dyes onto MnO_2/biomass micro-composite

These synthesized solar catalysts show potential to fragment microplastics in the environment. Also, the micro-composites are potential viable materials for the treatment of water contaminated with antibiotics and antiviral drugs.

Figure 42: Excursion with MSc Civil Engineering and Environmental Engineering students alongside my Host Professor (Prof. Dr. Brigitte Helmreich) to Garching Wastewater Treatment Plant on Wednesday, 4 August, 2021.

Dr. Omorogie was at the Chair between June and August. During his stay, he also received a grant from the Alexander von Humboldt Foundation. Therefore, he will be back from the middle of next year, this time for 18 months.

International Cooperation Partners

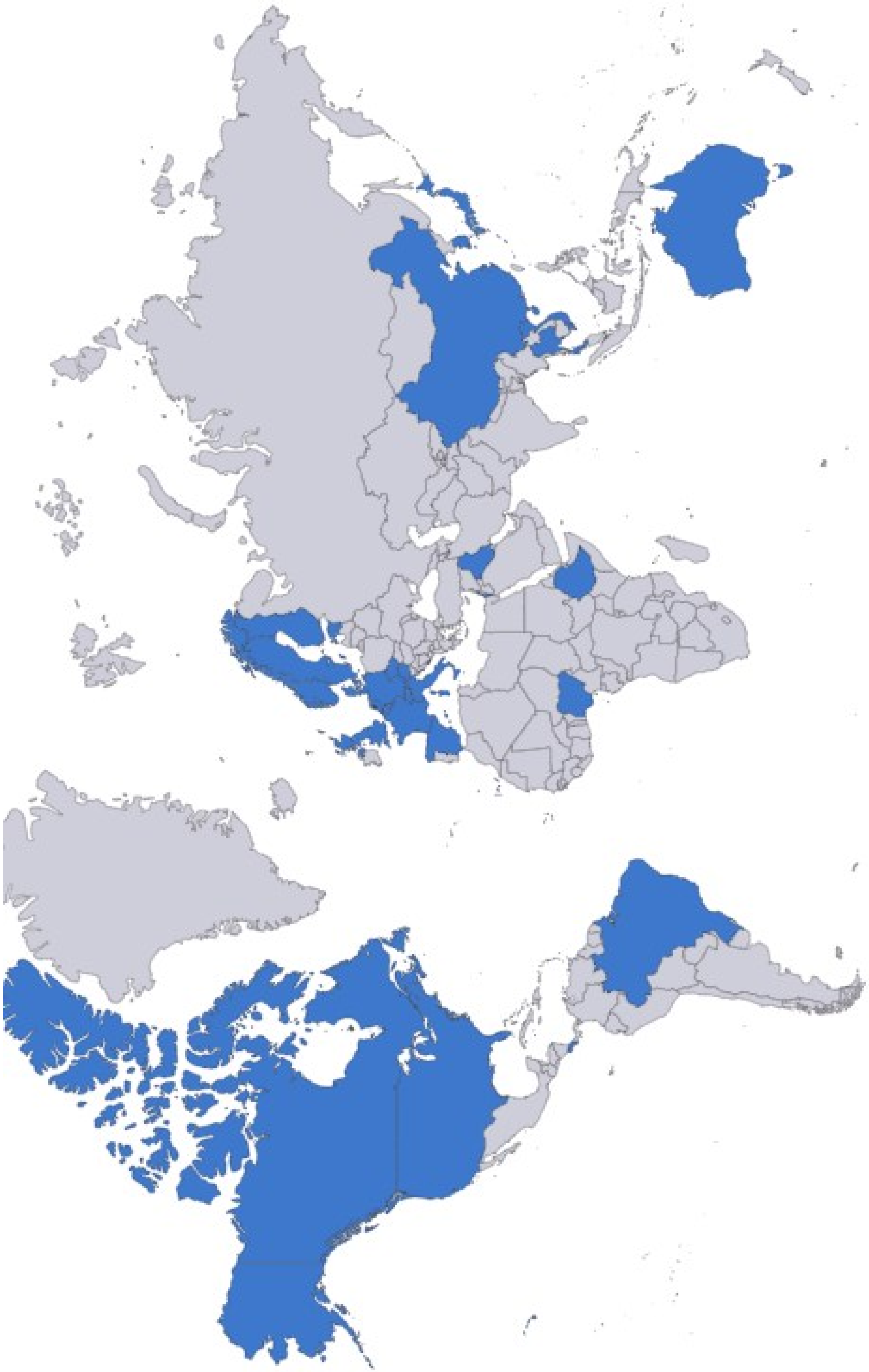

Figure 43. International partners.

Country	Institution
Australia	University of Queensland Curtin University University of New South Wales University of Sydney
Belgium	Flemish Institute for Technological Research Université catholique de Louvain University of Antwerp
Brazil	Universidade Federal de Minas Gerais Pontifícia Universidade Católica de Minas Gerais Universidade Federal da Bahia Universidade Federal de Viçosa Universidade Federal do Rio de Janeiro
Canada	Université du Québec à Chicoutimi Université Laval
China	Harbin Institute of Technology Tsinghua University
Costa Rica	University of Costa Rica
Czech Republic	Czech Academy of Sciences University of Chemistry and Technology, Prague Charles University
Denmark	Aarhus University Aalborg University University of Southern Denmark
Estonia	University of Tartu
Ethiopia	Addis Ababa University
Finland	University of Jyväskylä
France	Université de Montpellier
Japan	Yokohama National University Toho University Hosei University
Netherlands	Delft University of Technology
Nigeria	Adekunle Ajasin University, Akungba
Norway	University of Oslo
Singapore	Nanyang Technological University National University of Singapore
South Korea	Seoul National University Chonnam National University
Spain	University of Barcelona
Sweden	University of Gothenburg Swedish University of Agricultural Sciences Uppsala University Karolinska Institutet KTH Royal Institute of Technology Stockholm University Chalmers University of Technology
Switzerland	Swiss Federal Institute of Technology Lausanne Swiss Federal Institute of Technology Zurich
Thailand	Mae Fah Luang University
United Kingdom	Cranfield University Brunel University London The James Hutton Institute University of Aberdeen University of Plymouth Aberystwyth University
United States	University of Colorado Boulder Colorado School of Mines University of Arizona University of California at Berkeley University of Wisconsin-Madison University of Michigan, Ann Arbor

National & International Committees

DWA Working Groups

Brigitte Helmreich is spokesperson of the **DWA Working Groups ES-3.1** “Percolation of Rainwater” and member of **ES-3.7** “Decentralized treatment plants” and **ES-3.11** “Multifunctional areas”. She is member of the DWA Committee of Experts **ES-3** “Plant-Related Planning”, where she the deputy chairman. In addition, she is an active member of the **DWA Technical Committee IG-2** “Sector-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" and 'Water Reuse'. He continues to serve on the Management Committee of the **IWA Water Reuse Specialist Group**, as well as the **Strategic Council** of the International Water Association (IWA). Mr. Drewes continues to serve as a member of the BMG/Federal Environmental Agency **Drinking Water Commission**. He also served as spokesperson of the **Expert Commission** 'Water Supply in Bavaria' of the Bavarian State Government. He is the speaker of the expert commission 'Chemicals of Emerging Concern in Ambient Waters' of the **California State Water Resources Control Board, USA** and a member of the expert commission 'Proposed Criteria for Direct Potable Reuse in California' of the **National Water Research Institute (NWRI), USA**.

Uwe Hübner is an active member of the **DWA Committee of Experts KA-8.5** “Ozonation at Wastewater Treatment Plants”.

German Water Chemistry Society

Uwe Hübner is an active member of the Technical Committees *“Transformationsprozesse bei der biologischen Abwasserreinigung und Abwasserwiederverwendung”* and *“Oxidative Prozesse”* in the German **Water Chemistry Society**.

Christian Wurzbacher is an active member of the Technical Committee *“Pathogens and Antibiotic Resistant Bacteria in the Water Cycle”*, a subcommittee of the German **Water Chemistry Society**. The group develops the current state of knowledge and perspectives in dealing with pathogens in the water cycle.

Journals – Editors

Jörg E. Drewes serves since 2020 as the Associate Editor of the journal *ACS Environmental Engineering and Technology Water*.

Christian Wurzbacher is special editor of the journals *MycoKeys* and *Biodiversity Data Journal*.

Konrad Koch and **Uwe Hübner** are guest editors for the journal *Water* editing special issues on *“Biomethane Potential Tests - A Key Tool for Anaerobic Digestion Research and Practice”* and *“Oxidative Processes in Water and Wastewater Treatment Systems”*.

Workshops & Other Activities

The **Roland Mall Foundation** presented three gifted students from the field of water and environment each with a scholarship of €500/month for the entire standard period of study of the Master's program in 2021. The students (**Lilian Busse, Poojesh Bertram-Mohammadi** and **Thomas Obermaier**) were selected based on their previous accomplishments.

Sciencecyclists

In 2021, we collectively biked over 21,925 kilometers to and from the chair. This equates to 3.2 tons of CO_2 saved in comparison to an average car, and 8 tons of CO_2 in comparison to an economy flight. We aim to increase overall and individual contribution in 2022! Last year, Dr. Konrad Koch achieved the highest individual mileage, for which he was awarded the chair's Scienclist Cup.

Upcoming Events

32nd Water Technology Seminar, 23 February 2022, Online Seminar: Pathogenic and antibiotic resistant bacteria in the water cycle

In recent years, the spectrum of analytical methods for the identification and quantification of microorganisms and viruses (= bioanalytics) has developed rapidly. The quantification of bacteria with cultivation methods, which is often required by the legislator, is nowadays countered by modern methods that quickly identify the identity, quantity, vitality and diversity of microorganisms and viruses.

Specific pathogenic bacteria and viruses as well as antibiotic-resistant bacteria can be determined within a few hours. Omics methods such as next generation sequencing or microarrays enable highly differentiated analysis in the diversity of bacteria and viruses.

All these methods have become established in medical diagnostics or at least enable research at the highest level. For this reason, it should be possible to use these methods for microbiological water analysis in the future and transfer them into practice.

In our seminar we want to discuss the transfer from science to practice. It is extremely important that the new methods deliver reliable results.

Finally, the entirety of the water cycle should be considered with reference to humans and animals (One Health approach of the EU). This will become increasingly important, especially with regard to climate change and the limitation of water as a resource.

Registration via https://www.cee.ed.tum.de/sww/wts32/

49th Wastewater Engineering Seminar, July 5, 2022, Online seminar: Water Reuse - Potential and Applications in Germany

This virtual event gives an overview of current legal developments of water reuse in Europe and Germany and provides an insight into the potential of this water use underpinned by reports of applications and planning in Germany.

Publications

Peer-reviewed Journal Articles

1) Arcanjo, G.S.; Ricci, B.C.; dos Santos, C.R.; Costa, F.C.R.; Silva, U.C.M.; Mounteer, A.H.; Koch, K.; da Silva, P.R.; Santos, V.L.; Amaral, M.C.S. (2021): Effective removal of pharmaceutical compounds and estrogenic activity by a hybrid anaerobic osmotic membrane bioreactor – Membrane distillation system treating municipal sewage. Chemical Engineering Journal 416, 129151.
2) Bein, E.; Zucker, I.; Drewes, J.E.; Hübner, U. (2021): Ozone membrane contactors for water and wastewater treatment: A critical review on materials selection, mass transfer and process design. Chemical Engineering Journal 413, 127393.
3) Costa, F.C.R.; Ricci, B.C.; Teodoro, B.; Koch, K.; Drewes, J.E.; Amaral, M.C.S. (2021): Biofouling in membrane distillation applications - a review. Desalination 516, 115241.
4) Dos Santos, C.R.; Arcanjo, G.S.; de Souza Santos, L.V.; Koch, K.; Amaral, M.C.S (2021): Aquatic concentration and risk assessment of pharmaceutically active compounds in the environment. Environmental Pollution 290, 118049.
5) Duan, H.; Zhao, Y.; Koch, K.; Wells, G.F.; Zheng, M.; Yuan, Z.; Ye, L. (2021): Insights into Nitrous Oxide Mitigation Strategies in Wastewater Treatment and Challenges for Wider Implementation. Environmental Science & Technology 55 (11), 7208-7224.
6) Fajnorová, S.; Sprenger, C.; Hermes, N.; Ternes, T.A.; Sala, L.; Miehe, U.; Drewes, J.E.; Hübner, U. (2021): Assessment of Full-Scale Indirect Potable Water Reuse in El Port de la Selva, Spain. Water 13 (3), 325.
7) Fenner, K.; Elsner, M.; Lueders, T.; McLachlan, M.S.; Wackett, L.P.; Zimmermann, M.; Drewes, J.E. (2021): Methodological Advances to Study Contaminant Biotransformation: New Prospects for Understanding and Reducing Environmental Persistence? ACS ES&T Water 1 (7), 1541-1554.
8) Filter, J.; Zhiteneva, V.; Vick, C.; Ruhl, A.S.; Jekel, M.; Hübner, U.; Drewes, J.E. (2021): Varying attenuation of trace organic chemicals in natural treatment systems – A review of key influential factors. Chemosphere 274, 129774.
9) Funck, M.; Al-Azzawi, M.M.S.; Yildirim, A.; Knoop, O.; Schmidt, T.C.; Drewes, J.E.; Tuerk, J. (2021): Release of microplastic particles to the aquatic environment via wastewater treatment plants: The impact of sand filters as tertiary treatment. Chemical Engineering Journal 426, 130933.
10) Gondhalekar, D.; Drewes, J.E. (2021): Infrastructure shaming and consequences for management of urban WEF Security Nexus in China and India. Water 13 (3), 267.
11) Heeger, F.; Bourne, E.C.; Wurzbacher, C.; Funke, E.; Lipzen, A.; He, G.; Ng, V.; Grigoriev, I.V.; Schlosser, D.; Monaghan, M.T. (2021): Evidence for Lignocellulose-Decomposing Enzymes in the Genome and Transcriptome of the Aquatic Hyphomycete *Clavariopsis aquatica*. Journal of Fungi 7 (10), 854.
12) Hellauer, K.; Michel, P.; Holland, S.I.; Hübner, U.; Drewes, J.E.; Lauro, F.M.; Manefield, M.J. (2021): Inferring trophic conditions in managed aquifer recharge systems from metagenomic data. Science of The Total Environment 772, 145512.
13) Helmreich, B. (2021): Rainwater Management in Urban Areas. Water 13 (8), 1096.
14) Hollinger, C.; Astals, S.; Fruteau de Laclos, H.; Hafner, S.D.; Koch, K.; Weinrich, S. (2021): Towards a Standardization of Biomethane Potential Tests: a Commentary. Water Sci Technol 83 (1), 247–250.
15) Hübner, U.; Wolff, D.; Achermann, S.; Drewes, J.E.; Wick, A.; Fenner, K. (2021): Analyzing (initial) biotransformation reactions as an organizing principle to unravel the extent of trace organic chemical biotransformation in biofiltration systems. ES&T Water 1 (8), 1921-1931.

16) Kagami, M.; Seto, K.; Nozaki, D.; Nakamura, T.; Wakana, H.; Wurzbacher, C. (2021): Single dominant diatom can host diverse parasitic fungi with different degree of host specificity. Limnology and Oceanography 66 (3), 667-677.

17) Karakurt-Fischer, S.; Rien, C.; Sanz-Prat, A.; Szewzyk, R.; Hübner, U.; Drewes, J.E.; Selinka, H.C. (2021): Fate and transport of viruses within a high rate plug-flow biofilter designed for non-membrane based indirect potable reuse applications. ES&T Water 1 (5), 1229-1239.

18) Kluge, M.; Wauthy, M.; Clemmensen, K.E.; Wurzbacher, C.; Hawkes, J.A.; Einarsdottir, K.; Rautio, M.; Stenlid, J.; Peura, S. (2021): Declining fungal diversity in Arctic freshwaters along a permafrost thaw gradient. Global Change Biology 27 (22), 5889-5906.

19) Kluge, M.; Wurzbacher, C.; Wauthy, M.; Clemmensen, K.E.; Hawkes, J.A.; Einarsdottir, K.; Stenlid, J.; Peura, S. (2021): Community composition of aquatic fungi across the thawing Arctic. Scientific Data 8, 211.

20) Liguori, R.; Rommel, S.H; Bengtsson-Palme, J.; Helmreich, B.; Wurzbacher, C. (2021): Microbial retention and resistances in stormwater quality improvement devices treating road runoff. FEMS Microbes 2, xtab 008.

21) Lippert, T.; Bandelin, J.; Vogl, D.; Tesieh, Z.A.; Wild, T.; Drewes, J.E.; Koch, K. (2021): Full-Scale Assessment of Ultrasonic Sewage Sludge Pretreatment Using a Novel Double-Tube Reactor. ACS ES&T Engineering 2021 1 (2), 298-309.

22) Mohr, M.; Dockhorn, T.; Drewes, J.E.; Karwat, S.; Lackner, S.; Lotz, B.; Nahrstedt, A.; Nocker, A.; Schramm, E.; Zimmermann, M. (2021): Assuring water quality along multi-barrier treatment systems for agricultural water reuse. Journal of Water Reuse and Desalination 10 (4): 332–346.

23) Muntau, M.; Lebuhn, M.; Polag, D.; Bajón-Fernández, Y.; Koch, K. (2021): Effects of CO2 enrichment on the anaerobic digestion of sewage sludge in continuously operated fermenters. Bioresource Technology 332, 125147.

24) Paez-Curtidor, N.; Gondhalekar, D.; Drewes J.E. (2021): Application of the Water-Energy-Food Nexus Approach to the Climate-Resilient Water Safety Plan of Leh Town, India. Sustainability 13 (19), 10550.

25) Reichel, J.; Graßmann, J.; Knoop, O.; Drewes, J.E.; Letzel, T. (2021): Organic Contaminants and Interactions with Micro- and Nano-Plastics in the Aqueous Environment: Review of Analytical Methods Molecules 26 (4), 1164.

26) Ricci, B.C.; Arcanjo, G.S.; Moreira, V.R.; Lebron, Y.A.R.; Koch, K.; Costa, F.C.R.; Ferreira, B.P.; Lisboa, F.L.C.; Miranda, L.D.; de Faria, C.V.; Lange, L.C.; Amaral, M.C.S. (2021): A novel submerged anaerobic osmotic membrane bioreactor coupled to membrane distillation for water reclamation from municipal wastewater. Chemical Engineering Journal 414, 128645.

27) Rommel, S.H.; Stinshoff, P.; Helmreich, B. (2021): Sequential extraction of heavy metals from sorptive filter media and sediments trapped in stormwater quality improvement devices for road runoff. Science of The Total Environment 782, 14687.

28) Rossmann, K.; Clasen, R.; Münch, M.; Wurzbacher, C.; Tiehm, A.; Drewes, J.E. (2021): 2021 SARS-CoV-2 Crisis Management with a Wastewater Early-Warning System in the Bavarian District of Berchtesgadener Land, Germany. Deutsches Ärzteblatt International 118 (27-28), 479-480.

29) Schwaller, C.; Hoffmann, G.; Hiller, C.X.; Helmreich, B.; Drewes, J.E. (2021): Inline dosing of powdered activated carbon and coagulant prior to ultrafiltration at pilot-scale – Effects on trace organic chemical removal and operational stability. Chemical Engineering Journal 414, 128801.

30) Schwaller, C.; Keller, Y.; Helmreich, B.; Drewes, J.E. (2021): Estimating the agricultural irrigation demand for planning of non-potable water reuse projects. Agricultural Water Management 244, 106529.

31) Silva, A.F.R.; Brasil, Y.L.; Koch, K.; Amaral, M.C.S. (2021): Resource recovery from sugarcane vinasse by anaerobic digestion – A review. Journal of Environmental Management 295, 113137.

32) Spieler, M.; Muffler, L.; Drewes, J.E. (2021): Wasserrechtliche Rahmenbedingungen der Wasserwiederverwendung in Deutschland (Teil 2). Korrespondenz Abwasser 68 (1).

33) Strassert, J.; Wurzbacher, C.; Hervé, V.; Antany, T.; Brune, A.; Radek, R (2021): Long rDNA amplicon sequencing of insect-infecting nephridiophagids reveals their affiliation to the Chytridiomycota and a potential to switch between hosts. Scientific reports 11 (1), 396.
34) Vega-Garcia, P.; Schwerd, R.; Schwitalla, C.; Johann, S.; Scherer, C.; Helmreich, B. (2021): Leaching prediction for vertical test panels coated with plaster and mortars exposed under real conditions by a PHREEQC leaching model. Chemosphere 280, 130657.
35) Vinardell, S.; Astals, S.; Koch, K.; Mata-Alvarez, J.; Dosta, J. (2021): Co-digestion of sewage sludge and food waste in a wastewater treatment plant based on mainstream anaerobic membrane bioreactor technology: A techno-economic evaluation. Bioresource Technology 330, 124978.
36) Voigt, K.; James, T.Y.; Kirk, P.M.; Santiago, A.L.D.A.; Waldman, B.; Griffith, G.W.; Fu, M.; Radek, R.; Strassert, J.F.; Wurzbacher, C.; Jerônimo, G.H. (2021): Early-diverging fungal phyla: taxonomy, species concept, ecology, distribution, anthropogenic impact, and novel phylogenetic proposals. Fungal Diversity 109, 59-98.
37) Wünsch, R.; Mayer, C.; Plattner, J.; Eugster, F.; Wülser, R.; Gebhardt, J.; Hübner, U.; Canonica, S.; Wintgens, T.; von Gunten, U. (2021): Micropollutants as internal probe compounds to assess UV fluence and hydroxyl radical exposure in UV/H_2O_2 treatment. Water Research 195, 116940.
38) Zhiteneva, V.; Carvajal, G.; Shehata, O.; Hübner, U.; Drewes, J.E. (2021): Quantitative microbial risk assessment of a non-membrane based indirect potable water reuse system using Bayesian networks. Science of The Total Environment 780, 146462.
39) Zhiteneva, V.; Drewes, J.E.; Hübner, U. (2021): Removal of trace organic chemicals during long-term biofilter operation. ES&T Water 1 (2), 300-308.

Other Journal Articles and Book Contributions

1) Cao, L.; Wolff, D.; Liguori, R.; Wurzbacher, C.; Wick, A. (2021): Microbial biomass, composition, and functions are responsible for the differential removal of trace organic chemicals in biofiltration systems. bioRxiv.
2) Drewes, J.E. (2021): Klimawandel und Wasserverfügbarkeit. M. Ferber, H. Kaul (Hrsg). Bekenntnisse zur Verantwortung für die Umwelt. Hanns-Seidel Stiftung. Lau Verlag. 277-294.
3) Drewes, J.E.; Knoop, O. (2021): Neue Anforderungen an die Trinkwasseraufbereitung durch perfluorierte Verbindungen (PFAS)?. GWF Wasser/Abwasser 162 (4), 17-18.
4) Gondhalekar, D.; Hu, H.Y.; Chen, Z.; Tayal, S.; Bekchanov, M.; Sauer, J.; Vrachioli, M.; Al-Azzawi, M.; Drewes, J.E.; Patalong, H.; Uhl, H.D.; Grambow M. (2021): The emerging environmental economics of the Water-Energy-Food Nexus with water reclamation with resource recovery as key: the case of China, India and Germany. The Oxford Encyclopedia of Environmental Economics, Oxford University Press.
5) Helmreich, B., Müller, J. (2021): Die öffentliche Kanalisation in Bayern – Zustand und Investitionsbedarf. Mitgliederrundbrief, DWA-Landesverband Bayern 44, 2, S. 20-22.
6) Ho, J.; Stange, C.; Suhrborg, R.; Wurzbacher, C.; Drewes, J. E.; Tiehm, A. (2021): SARS-CoV-2 wastewater surveillance in Germany: long-term PCR monitoring, suitability of primer/probe combinations and biomarker stability. medRxiv.
7) Kluge, M.; Wurzbacher, C.; Wauthy, M.; Clemmensen, K.E.; Hawkes, J.; Einarsdottir, K.; Stenlid, J.; Peura, S. (2021): Fungal community composition along a gradient of permafrost thaw. bioRxiv.
8) Knoop, O.; Schwaferts, C.; Al-Azzawi M.S.M.; Kunaschk, M.; Funck, M.; Türk, J.; Meier, F.; Elsner, M.; Ivleva, I.P.; Drewes, J.E. (2021): Analytik von Mikro- und Submikropartikeln aus Wasserproben: Status Quo und Ausblick, Korrespondenz Wasserwirtschaft 14, 2021, Nr. 3.
9) Knoop, O.; Drewes, J.E. (2021): Neue Anforderungen an die Trinkwasseraufbereitung durch perfluorierte Verbindungen (PFAS)? (ISSN: 0942-914X), Berichte aus der Siedlungswasserwirtschaft Technische Universität München, München.

10) Liguori, R.; Rommel, S.H.; Bengtsson-Palme, J.; Helmreich, B.; Wurzbacher, C. (2021): Microbial retention and resistances in stormwater quality improvement devices treating road runoff. bioRxiv.

11) Oladoja N.A.; Helmreich B. (2021): Oxyanions in Aqua Systems—Friends or Foes? In: Oladoja N.A., Unuabonah E.I. (eds) Progress and Prospects in the Management of Oxyanion Polluted Aqua Systems. Environmental Contamination Remediation and Management. Springer, Cham. Online-ISBN: 978-3-030-70757-6.

12) Roßmann, K.; Großmann, G.; Frangoulidis, D.; Clasen, R.; Münch, M.; Hasenknopf, M.; Wurzbacher, C.; Tiehm, A.; Stange, C.; Ho, J.; Woermann, M. (2021): Innovative SARS-CoV-2 crisis management in the public health sector: Corona dashboard and wastewater surveillance using the example of Berchtesgadener Land, Germany. Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz.

Conferences (Oral Presentations)

1) Drewes, J.E. (2021): Ist die Wasserwiederverwendung eine Planungsoption für die zukünftige Wasserwirtschaft in Deutschland? 54. Essener Tagung. 9.-10. June 2021, online.

2) Drewes, J.E. (2021): Klimawandel und Trockenheit – Konsequenzen für eine sichere Wasserzukunft in Bayern. 6. Seeoner Begegnung ‚Lebenselexier Wasser', Bayerische Staatskanzlei. 14. June 2021.

3) Drewes, J.E. (2021): Neue Grenzwerte für Per- und polyfluorierte Alkylverbindungen (PFAS) und Relevanz für die Trinkwasseraufbereitung. 29. Wasserhygienetage. 4.-5. February 2021, online.

4) Drewes, J.E. (2021): Per- und polyfluorierte Alkylverbindungen (PFAS): Konventionelle Verfahren der Trinkwasseraufbereitung. 31. Wassertechnisches Seminar an der TU München. 3. March 2021, online.

5) Drewes, J.E. (2021): Wasserwiederverwendung in Europa: Neue Entwicklungen, Herausforderungen und Chancen. Informationsveranstaltung im Projekt AQARES. 20. January 2021, online.

6) Drewes, J.E.; Hiller, C.; Schwaller, C. (2021): Internationale Aktivitäten zur Begrenzung und Verbreitung von Antibiotikaresistenzen über Abwasser in die Umwelt. DGMT Stakeholder Dialog – Multiresistente Keime im Abwasser und Oberflächenwasser. 2. March 2021, online.

7) Gondhalekar, D. (2021): Adopting water reclamation with inte- grated resource recovery as the cornerstone to plan climate change-resilient cities. Webinar on Integrated Water and Wastewater Management. 22. March 2021, online.

8) Gondhalekar, D. (2021): Nexus City: Water reclamation and resource recovery towards zero carbon urban development, Asian Development Bank Water Sector Group, Manila. 16. September 2021, online.

9) Gondhalekar, D. (2021): Planning the Urban Water-Energy-Food (WEF) Nexus Training Session / Innovation Lab, UN-Habitat Innovate4Cities conference. 14. October 2021, online.

10) Gondhalekar, D. (2021): Towards Zero Carbon or even better: Rejuvenation Cities, MIT Alumni Association "Climate Change Matters" Symposium, Stuttgart. 16. October 2021.

11) Gondhalekar, D. (2021): Urban water reclamation and reuse as a key Water-Energy-Food (WEF) Nexus opportunity in Munich, Germany and Leh, India. TREE of LIFE Landscape Webinar Series, University of Tehran, Iran. 24. February 2021, online.

12) Gondhalekar, D. (2021): Urban water reclamation and reuse as key Water-Energy-Food (WEF) Nexus synergy potential, 9th German-Brazilian Dialogue on Science, Research & Innovation on „Cities & Climate ", German House of Research & Innovation (DWIH), São Paulo. 17. May 2021, online.

13) Gondhalekar, D.; Saravanan, V.S.; Drewes J.E. (2021): Zero Carbon City Munich, through Water-Energy-Food (WEF) Nexus-based infrastructure development. German Sustainability Science Summit. 9. July 2021, online.

14) Hafner, S.; Astals, S.; Fruteau de Laclos, H.; Koch, K.; Weinrich, S.; Holliger, C. (2021): Making BMP measurement more reproducible: Results, recommendations, and resources from the IIS-BMP project. 5th International Conference on Monitoring & Process Control of Anaerobic Digestion Processes. 23-25. March 2021, online.
15) Helmreich B. (2021): Überflutungsvorsorge durch nachhaltiges Regenwassermanagement. Bayerischer Gemeindetag, Oberhaching. 1. December 2021.
16) Helmreich, B (2021): Wie gelingt eine nachhaltige Regenwasserbewirtschaftung. Campus Talks. April 2021, TV report.
17) Helmreich, B. (2021): Aktueller Stand DWA-A 138-1. Grundstückentwässerungstage, Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., Hennef. 03.-04. February 2021, online.
18) Helmreich, B. (2021): Aktueller Stand DWA-A 138-1. RegenwasserTage, Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., Hennef. 22.-23. June 2021, online.
19) Helmreich, B. (2021): Forschung und Normen bei Versickerungsanlagen. Fortbildungsreihe Klimagerechtes Bauen, München. 26. January 2021, online.
20) Helmreich, B. (2021): Regenwasserversickerung ins Grundwasser nach dem DWA-A 138-1 – Was ist neu? 48. Abwassertechnisches Seminar Regenwasserbewirtschaftung in Zeiten des Klimawandels, Garching. 14. July 2021, online.
21) Helmreich, B. (2021): Tools der wasserresilienten Stadt – Regenwasserbewirtschaftung. Public Planning Lab, Interdisziplinäres Seminar des Baureferendariats, Bayerischen Staatsministeriums für Wohnen, Bau und Verkehr. 6. December 2021, online.
22) Helmreich, B. (2021): Vorreinigung von Niederschlagsabflüssen im Straßenraum. Seminar Blue Green Streets -Regenwasserbewirtschaftung an urbanen Baumstandorten. HafenCity Universität Hamburg, Hamburg. 15.-16. February 2021, online.
23) Helmreich, B.; Müller, J. (2021): Neue Ergebnisse zum Zustand der Kanalisation in Bayern. DWA-Landesverbandstagung Bayern, Wasserwirtschaft im Blickpunkt – Daseinsvorsorge in Zeiten des Wandels, Weiden. 5.-6. October 2021, online.
24) Lebuhn, M.; Mößnang, B.; Strübing, D.; Koch, K. (2021): Convergent development of microbiomes from different inocula in thermophilic biomethanation of H_2 and CO_2. International Symposium on Anaerobic Microbiology. 16.-17. June 2021, online.
25) Lesch, H.; Helmreich, B.; Pauleit S. (2021): Zukunft Schwammstadt: wie wir mit Wetter-Extremen leben können. Morgen beginnt heute - der Umwelt und Verbraucher Podcast. 19. January 2021, Podcast.
26) Lippert, T.; Helmreich, B.; Drewes, J. (2021): Innovative Konzepte zur Elimination organischer Spurenstoffe am Beispiel PFAS - Projekt „Geschlossener Wasserkreislauf in der Industrie – Abwasserfreie Industrieproduktion". 16. Bayerische Wassertage 2021, Augsburg. 24.-25. March 2021, online.
27) Lippert, T.; Lowicki, M.; Helmreich, B.; Drewes, J.E.; Frank, D.; Track, T. (2021): Entwicklung zukunftsfähiger Verfahrenskombinationen zur PFAS-Elimination in Industrieabwässern unter Nutzung von Multi Criteria Decision Aid (MCDA) Tools. Industrietage Wassertechnik. 24. November 2021, online.
28) Nawaz, A.; Wurzbacher, C. (2021): Back to the Future: Exploration and Identification of Aquatic Fungi. Symposium for European Freshwater Science. July 2021, online.
29) Sperle, P.; Drewes, J.; Wurzbacher, C.; Skibinski, B. (2021): UVC-LED based pretreatment for biofouling control in desalination processes with thin-film composite membranes. International Conference on UV LED Technologies & Applications. April 2022, online.
30) Stüer-Patowsky, K.; Gega, E.; Wurzbacher, C. (2021): Progressive Succession of Fungi in Biofilms of Down-flow Hanging Sponge Reactors. World Microbe Forum. June 2021, poster online.
31) Vega-Garcia, P.; Schwerd, R.; Helmreich, B. (2021): Development of a model to assess the environmental properties of common outdoor plasters and mortars. 15th International Conference on Urban Drainage, Melbourne, Australia. 25.-28. October 2021, online.

Theses

Habilitation

Hübner, Uwe: Advanced water treatment processes and water recycling.

Doctoral Dissertations

1) Bandelin, Jochen: Increasing the energy efficiency of ultrasonic pre-treatment systems in wastewater treatment plants.
2) Lippert, Thomas: Sewage sludge disintegration using innovative ultrasound reactors with surface transducers - Performance assessment and optimization of operating conditions.
3) Rommel, Steffen: Influencing Factors on the Treatment of Road Runoff using Decentralized Stormwater Quality Improvement Devices.
4) Wahman, Rofida: Pathway Effect Studies of Different Environmental Pollutants on *Lemna minor* and *Phragmites australis* Metabolism Using Polarity-Extended Chromatographic Separation with Mass Spectrometric Detection.

Master's Theses

1) Baba, Mohammed Majiya: Comparison of the Performance of Biocarriers in Anaerobic Trickle Bed Reactors.
2) Bamgboye, Taiwo Temitope: Wastewater Reclamation and Reuse in Sub Saharan Africa Countries: Challenges and Opportunities in Nigeria
3) Becker, Lukas: Opportunities and Challenges of Producing Avocados in Central Europe: WEF Nexus Potential in Bavaria and the Munich Metropolitan Region.
4) Betianu, Radu Mihai: Biological Transformation of Trace Organic Chemicals in a Sequential Managed Aquifer Recharge Technology System Using Algae as the Intermediate Oxidation Process.
5) Böttcher, Theresa: Impact of CO2 Enrichment on Anaerobic Digestion Performance and Stability at High Organic Loading Rates.
6) Carter, Kaitlyn: Isostructural water-stable metal-organic frameworks (MOFs) as PFAS adsorbents: Correlation between structure and performance.
7) Degenhart, Julia: Critical review of pollutants in stormwater runoff of non-metal roofs.
8) Fianelli, Francesco: Restart of a Thermophilic Trickle Bed Reactor and Optimization of Process Conditions.
9) Franco, Lucas: Formulating a system dynamics model to characterize the urban water-energy-food nexus: A case study of the Maxvorstadt neighbourhood in Munich, Germany.
10) Galster, Susanne: Copper and zinc as roofing materials – A review on the occurrence and mitigation measures of runoff pollution.
11) Janicek, Maximilian: Determination of infiltration water reduction potential by remedying structural damage in the main sewer.
12) Hasan, Syed Sarfraz: Cost benefit analysis of WEF Nexus approach in Maxvorstadt, Munich, Germany: introducing decentralized water reclamation with resource recovery as a dual system.
13) Hernandez Robles, Gabriel: Feasibility of energy generation with biogas at the household level; assessing the impact of anaerobic co-digestion of waste activated sludge and food waste.
14) Karabulut, Özge: Utilization of agricultural by-products as feedstock for biogas production: Effect of inoculum source and pretreatment method on biogas potential and biogas production.

15) Klier, Rebecca: Wastewater disposal and drinking water supply in alpine terrain exemplified by Watzmann.
16) Kölle, Simon: Validation of System Design for Novel Ozonation (18O3) Labeling Method.
17) Kurz, Johannes: Evaluation of inhibition effects of volatile fatty acids in biochemical methane potential tests.
18) Lang, Camila: The design of a water reclamation system using constructed wetlands: a case study of Dar, Niger
19) Lechner, Johann: Test, review and evaluation of a new type of calculation method for long-term storage of stormwater runoff as a measure to improve the water balance and the adaption to climate change.
20) Lenert, Charlotte: Conceptualization and Construction of an Automated Water Sampling System for the SMARTplus Bioreactor.
21) Lok, Cheuk Sze Chelsea: Modelling the environmental fate and behavior of transformation products of biocides used in façades external thermal insulation composite systems (ETICS).
22) Lowicki, Maximilian: Identification of suitable treatment methods for PFAS-containing wastewaters of the chemical industry.
23) Marciano, Pia: Towards Water-Energy-Food Balance Assessment in Coimbatore City, India.
24) Marhoon, Ahmed: COVID-19, the Environment and Sustainability: impacts, implications and the transition to a green economy.
25) Md, Yasin: Improved Gas Flow Conditions in an Anaerobic Trickle Bed Reactor in a Co-Current Configuration.
26) Mirlach, Andreas: Establishing a characterization procedure for reflecting UVC reactors using actinometry and biodosimetry.
27) Mondorf, David: The Water-Energy-Food Security Nexus in the Kenyan-Ugandan border region: Impact of surface water quality on drinking water supply in the Sio-Malaba-Malakisi River Basin.
28) Nieß, Daniel: Newly Established Low-complexity Model Microbial Communities - Growth Influencing Factors & Characteristics of TOrC Biodegradation.
29) Paez-Curtidor, Natalie: Application of the Water-Energy-Food Nexus in the formulation of a Climate-Resilient Water Safety Plan for Leh Town, India.
30) Petersen, Sophie: Ozonation of gabapentin: Reaction kinetics and the formation of transformation products in an aqueous environment.
31) Röschert, Yul: Cataloging and analysis of multifunctional retention measures in the context of the development of water-sensitive settlements.
32) Rossmanith, Christian: Treatment of wastewater from epoxy resin production.
33) Shahrour, Mahmoud: Discharge Time Series Generation for Hydropower "urbs" Model Case Study: Europe.
34) Stoll, Clara: Concept for the improvement of drinking water quality at natural springs in developing countries.
35) Stoll, Jonas: Review of the state-of-the-art in vacuum technologies and guideline for the replacement of water ring pumps by dry vacuum pumps.
36) Uchaikina, Anna: Variation of process parameters to enhance the efficiency of a wastewater electrolysis cell with boron-doped diamond electrodes.
37) Vongvichra, Nay: Remaining sorptive capacity of a filter medium and the effect of de-icing salts on heavy metal remobilization in treatment of road runoff.

Study Projects

1) Andalib, Afrina: Analyzing mass transfer efficiency and hydroxyl radical exposure for porous and non-porous membrane contactors applied for in-situ ozonation and peroxone treatment of groundwater flow.
2) Asamoah, Kwadwo Yeboah: Proposed Water Energy Food Nexus scheme for Boki, Niger.
3) Becker, Lukas: Restart of a Lab-Scale Continuous Anaerobic Digestion Experiment and Establishment of Steady-State Conditions.
4) Bergmann, Felix: Heavy precipitation simulation and irrigation calculation during dry periods based on a water management concept for a residential neighborhood of the future.
5) Basak, Nirjhar: Renewable energy potential in Leh, India: an assessment using the Water-Energy-Food Nexus framework
6) Borges de Mendonça, Rodrigo: Recommissioning and Documentation of a Bench-Scale Flat Sheet NF/RO Membrane System.
7) Bruhse, Matthias: Influence of Dissolved Organic Matter on the Heavy Metal Adsorption Capacity of Filter Media Used in Stormwater Quality Improvement Devices.
8) Castillo Nolte, AlejandroUrban Community Gardens as a strategy for Climate Change attenuation in the context of urban food production.
9) Colina, Andrijana: Developing use of unpotable water from the Natural Decentralized Wastewater Treatment pilot plant in Leh, India, with focus on agricultural opportunities, water reuse efficiency and economic potential.
10) Fokkens, Kevin: Meso to Nanoscale CFD Simulations of Tubular Ultrafiltration.
11) Eder, Simon: Use of multifunctional soils in decentralized infiltration systems such as infiltration swales in urban areas - A literature review.
12) Gega, Eva: Mitigation strategy and monitoring of control measures for developing a Water Safety Plan for Leh, India.
13) Haas Goschenhofer, Sophie: Water balance modeling of heavy rain events based on a water management concept for a residential neighborhood of the future.
14) Hillebrand, Veronika: Investigation on the state of internal power supply in wastewater treatment plants.
15) Irshad, Umar: Nutrient Requirement and microbial biocenosis in Anaerobic Trickle Bed Reactors.
16) Kaperoni, Marina: C40 Competition: Students Reinventing Cities – Sustainable Buildings in Balvanera Sur, Buenos Aires
17) Kim, Jiwon: Reviving Balvanera Sur - Water, Green Infrastructure, and Mobile Application
18) Knabl, Magdalena: Possible impacts of urban and agricultural irrigation with reclaimed water on the related ecological system.
19) Kurz, Johannes: Suitability testing of supermarket products as positive controls for biochemical methane potential tests.
20) Kordetzky, Christina: Evaluating the effect of pre-filtration on the efficiency of ozonation at the WWTP Gut Marienhof
21) Lang, Camilla: Identification of Hazards and Assessment of Risks for Leh‘s Water Safety Plan, India.
22) Nieß, Daniel: Cultivation and growth influencing factors of 18 aquatic fungi, and model microbial systems.
23) Özal, Göksu: Literature review - PFAS treatment methods - Adsorption & Separation Technologies.
24) Ortega Fuerte, Andrea: Identification and Classification of Water-Energy-Food Nexus Hubs in Latin America.
25) Pakta, Arsa: Literature review and collaboration with Greening Campus Initiative of United Nations Environment Program (UNEP) to make Technical University of Munich (TUM) sustainable.

26) Philips, Harsha: Study and evaluate modeling of environmental fate of glyphosate and its main metabolite aminomethylphsphonic acid (AMPA).
27) Prasad, Meenakshi: Methods for PFAS degradation – A literature review.
28) Rocha Santos, Giovanni: Management of organotin emissions in the plastic industry.
29) Röschert, Yul: Cataloging and analysis of multifunctional retention measures in the context of water-sensitive residential development.
30) Rossmanith, Christian: Reduction of TOC from saline industrial wastewater using adsorption.
31) Saeed, Areeba: Integrating Waste Management and Recycling Concepts for a Resilient and Liveable Balvanera Sur, Buenos Aires (C40 Competition)
32) Shaaban, Safenaz: Assessing the production of biochemical methane potential and hydrolysis rate constant for various solid wastes in different operating conditions.
33) Shadab, Saba: Decarbonising public buses with biogas in the city of Lille, Växjö and Augsburg: A WEF case scenario.
34) Souf, Amr: Assessing the Effect of Different Pre-Treatment Schemes on the Adsorption Capacity of Secondary-Effluent's Trace Organic Chemicals onto Powdered Activated Carbon.
35) Speer, Anna: Continuation of the model construction of a dirt load calculation for the town Neuburg an der Donau.
36) Stoll, Jonas: Utilization of instruments for the asset value preservation of water supply and wastewater disposal infrastructures in the European countries Austria and Switzerland.
37) Yasin, Md: Gas Flow Conditions in a Trickle Bed Reactor.

Bachelor's Theses

1) Alt, Benedikt: Mycobiome (fungal populations) in natural and constructed Wetlands.
2) Appelmann, Philipp: Hydroponic Agriculture.
3) Höbenreich, Klara: Analysis of the input and output measurements of the Zweckverbands Klärwerk Steinhäule and the Zweckverbands Klärwerk Steinhäule.
4) Holzer, Joshua: Elimination of trance organic chemicals at the WWTP Steinhäule – regulatory framework and evaluation of long-term monitoring of from powdered activated carbon dosing.
5) Jesus, Jessica: Trace organic compounds from wastewater treatment plants in relation to the microbial cell and their degradation possibilities.
6) Kick, Daniel: Use of tree trenches in the climate change adaptation in urban areas.
7) Kleber, Max: Green roofs for climate adaptation in settlement areas – opportunities and risks.
8) Kolb, Amelie: Membrane-assisted liquid-liquid extraction of astaxanthin from the microalgae *Haematococcus pluvialis.*
9) Kreitmair, Tobias: Investigations to the influence of the water matrix on the disinfecting efficiency of ozone in municipal sewage treatment plants.
10) Mettin, Ramona: State-specific regulations for stormwater management in Germany.
11) Pena Islas, Maria Fernanda: Comparison of Biogas Upgrading in Ex-situ Biological Methanation Reactors.
12) Rennett, Nina: Evaluation of long-term monitoring data of an optimized remediation plant for PAH-contaminated groundwater.
13) Schelkopf, Melanie: Conceptual study of the recovery of phosphorus as vivianite from waste water treatment plant.
14) Steinert, Anna: Wastewater-based epidemiology for monitoring the SARS-CoV-2 pandemic.
15) Stoß, Simon: Researching polar compounds originating from shower gels to augment compound database.
16) Weigenthaler, Verena: Climate Adaptation in Settlements - Concept of Water-Sensitive Urban Development as a Measure of Water Management.

Dissertations and Awards

Congratulations to **Dr.-Ing. Thomas Lippert** for successfully defending his dissertation, titled *"Sewage Sludge Disintegration Using Innovative Ultrasound Reactors With Surface Transducers - Performance Assessment and Aptimization of Operating Conditions"* on March 10th 2021. His committee members included Dr. Camilla Braguglia (Italian National Research Council), Prof. Jörg E. Drewes and PD Dr. Konrad Koch.

Figure 44: Dissertation committee of Dr.-Ing. Thomas Lippert (Dr. Braguglia joined remotely).

Figure 45: Dissertation committee of Dr.-Ing. Steffen Rommel (Prof. Dittmer joined remotely).

Congratulations to **Dr.-Ing. Steffen Rommel** for successfully defending his dissertation, titled *"Influencing Factors on the Treatment of Road Runoff using Decentralized Stormwater Quality Improvement Devices"* on May 7th, 2021. His committee members included Prof. Brigitte Helmreich, Prof. Ulrich Dittmer, TU Kaiserslautern, Prof. Markus Disse, TUM, and Prof. Jörg E. Drewes.

Congratulations to **Dr.-Ing. Jochen Bandelin** for successfully defending his dissertation, titled *"Increasing the Energy Efficiency of Ultrasonic Pre-treatment Systems in Wastewater Treatment Plants"* on July 2nd, 2021. His committee members included Prof. Lise Appels (KU Leuven, Belgium) and PD Dr. Konrad Koch, and Prof. Jörg E. Drewes.

Figure 46: Dissertation committee of Dr.-Ing. Jochen Bandelin (Prof. Appels joined remotely).

Figure 47: Dissertation committee of Dr. rer. nat. Rofida Wahman.

Congratulations to **Dr. rer. nat. Rofida Wahman** for successfully defending her dissertation, titled *"Pathway Effect Studies of Different Environmental Pollutants on Lemna minor and Phragmites australis Metabolism Using Polarity-Extended Chromatogra-phic Separation with Mass Spectrometric Detection"* on September 23rd, 2021. Her committee members included Dr. Thomas Letzel , Prof. Peter Schröder (Helmholtz Zentrum München) and Prof. Jörg E. Drewes.

We are pleased to present Dr.-Ing. Sema Karakurt-Fischer with the 2021 Doctoral Award of the Bund der Freunde der TU München e.V. for her dissertation.

Figure 48: Award ceremony for the dissertation award 2021 to Dr.-Ing. Sema Karakurt-Fischer by the Bund der Freunde der TU München e.V.

Teaching

The Chair of Urban Water Systems Engineering offers a wide range of different courses for the Bachelor study program *Umweltingenieurwesen* and *Bauingenieurwesen* 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 2021, the following lectures were offered:

Summer Term

Bachelor

- Grundlagen Ökologie: Knoop, Oliver
- Kreislaufwirtschaft und Werkstoffe für nachhaltiges Bauen: Koch, Konrad
- Mikrobiologie: Wurzbacher, Christian
- Projektkurs Siedlungswasserwirtschaft: Drewes, Jörg
- Thermodynamik und Energietechnik Übung: Hübner, Uwe
- Thermodynamik und Energietechnik: Hübner, Uwe
- Umweltanalytik: Knoop, Oliver
- Umweltrecht: Spieler Martin (TUM-External Lecturer)

Master/PhD

- Advanced Water Treatment Engineering and Reuse: Drewes, Jörg
- Anaerobic Treatment and Energy Recovery: Koch, Konrad
- Applications of Urban Climate: Katzschner, Lutz (TUM-External Lecturer)
- Bewirtschaftung von Kanalnetzen und Regenwassermanagement: Helmreich, Brigitte
- Doktoranden und Masteranden Kolloquium – Proaktiv: Drewes, Jörg; Helmreich, Brigitte; Koch, K., Hübner, Uwe; Knoop, Oliver; Wurzbacher, Christian; Keilman-Gondhalekar, Daphne
- Industrial Wastewater Treatment and Reuse: Helmreich, Brigitte
- PhD Seminar SiWaWi: Drewes, Jörg; Koch, Konrad
- Planning the Urban Water-Energy-Food Nexus, lecture & project: Keilman-Gondhalekar, Daphne
- Technical Communication Skills in Water and Wastewater Treatment Engineering: Koch, Konrad
- Unit Operations Laboratory on Advanced Water Treatment: Hüber, Uwe
- Wastewater Treatment: Koch, Konrad

Winter Term

Bachelor

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

Master/PhD

- Aquatic Microbiology: Wurzbacher, Christian
- Design and Operation of Wastewater Treatment Plants: Athanasiadis, Konstantinos (TUM-Lehrbeauftragter); Böhm, Bernhard (TUM-External Lecturer)
- Doktoranden und Masteranden Kolloquium – Proaktiv: Drewes, Jörg; Helmreich, Brigitte; Koch, Koch, Hübner, Uwe; Knoop, Oliver; Wurzbacher, Christian; Keilman-Gondhalekar, Daphne
- Engineered Natural Treatment Systems: Hübner, Uwe
- Hydrochemistry Laboratory: Knoop, Oliver; Helmreich, Brigitte; Petz, Susanne; Hübner, Uwe; Koch, Konrad
- Hydrochemistry: Helmreich, Brigitte
- Modeling of Aquatic Systems: Koch, Konrad
- PhD Seminar SiWaWi: Drewes, Jörg; Koch, Konrad
- Planungs- und Genehmigungsverfahren nach deutschem und europäischem Wasserrecht: Spieler, Martin (TUM-External Lecturer)
- Statistisch-stochastische Prognosen des baulich-betrieblichen Zustands von Entwässerungssystemen: Raganowicz, Andrzej (TUM-External Lecturer)
- Technical Communication Skills in Water and Wastewater Treatment: Drewes, Jörg; Koch, Konrad
- Unit Operations Laboratory on Advanced Water Treatment: Hübner, Uwe; Bein, Emil; Ilic, Nebojsa; Sierra Olea, Millaray
- 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.

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

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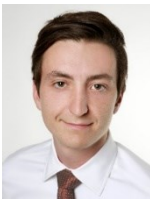

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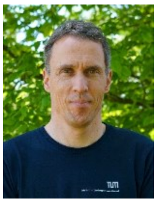

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