COMBINATION OF NEAR-NATURAL AND INNOVATIVE WASTEWATER TREATMENT AS AN EFFECTIVE COMPONENT OF SUSTAINABLE WATER RESOURCE PROTECTION IN RURAL AREAS

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A major challenge of the present and near future for rural municipalities to major cities is climate change and, in particular, how to deal with weather extremes. Climate projections and projects of different institutions, including Hof University of Applied Sciences, show that the mentioned challenges have an impact on different levels and tasks of a municipality, of which the aspect of water management is central..

On the one hand, the increasing risk of flooding due to increased evapotranspiration and the resulting intensified heavy rainfall events. On the other hand, due to the increasing decline of natural water resources by human use, increased evapotranspiration that safe drinking water supply and supply of urban green areas is becoming increasingly difficult. While urban planning, urban and regional infrastructure planning and issues of urban water management have been treated independently of each other so far, sustainable climate adaptation requires the networking of the different disciplines. But even within urban water management, wastewater treatment and drinking water supply are still considered separately. However, in view of increasing water consumption in times of prolonged drought and the simultaneous decline of groundwater reservoirs and river water levels, this separation must be eliminated and the substitution of drinking water by treated wastewater for suitable purposes, e.g. irrigation within the city or for groundwater recharge, must be integrated into the system. Increasingly, the topic of wastewater reuse is also being discussed in formerly water-rich countries such as Germany and the implementation of the new EU Regulation 2020/741 in technical solutions is being driven forward [1]. The combination of near-natural and new innovative wastewater systems opens up new possibilities, especially in financially weak small and medium-sized municipalities, to build up a sustainable water resource security and to operate it safely with the available financial and human resources.

Transformation of conventional wastewater planning into an important building block in dealing with weather extremes

Until now, wastewater planning has mostly been carried out by experts from a conventional point of view. The lack of resilience of this rigid approach is highlighted by the shift in weather extremes. In January 2023, the KOSTRA atlas, the basis for calculating the amount of rain to be handled by the stormwater infrastructure, was adjusted with current rainfall series. This adjustment, in most cases an increase of the design rainfall, means on the one hand that future stormwater management systems will be larger, but on the other hand also that the infrastructure built so far is not sufficiently dimensioned for future rain events.

Although Germany has formulated important goals for holistic water and wastewater planning with its National Water Strategy [2], these plans do not yet contain any further considerations in the sense of a holistic concept for dealing with weather extremes. Key aspects of the German National Water Strategy that should also be considered in wastewater planning are:

- Conflict of objectives between wastewater disposal and drinking water supply, when discharges from wastewater treatment plants can lead to changes in water quality in surface waters, especially during low-water periods, and thus contribute to the eutrophication of surface waters.

- Alternative water resources - e.g. industrial and rainwater use, treated municipal wastewater must be included in regional water use concepts to conserve scarce freshwater resources, taking health and environmental protection aspects into account.
- During the climate crisis, prolonged periods of drought are expected. Therefore, the development of additional, alternative water sources must be promoted, taking strict account of legal, hygienic and ecological concerns. Irrigation of urban green with treated wastewater, usage of service water, rainwater or treated greywater in households, public facilities and industry, as well as recirculation of process water are alternative routes to substitute drinking water.
- Especially at low water levels in water bodies, discharges of treated wastewater cause significant pollution, e.g. by pharmaceuticals or biocides. Likewise, there is pollution during heavier precipitation due to untreated combined sewer overflow.
- One measure to reduce the discharge of hazardous substances is to adapt the retention capacities of wastewater treatment plants to the expected more frequent occurrence of heavy rain events.
- The various challenges can sometimes be in tension with each other, e.g. because higher demands on the purification performance of wastewater treatment plants can be associated with increased energy consumption. To meet these challenges, it is necessary, on the one hand, to counteract the obsolescence and loss of value of existing infrastructures through continuous and sufficient investment in water infrastructure. On the other hand, the potentials of available intelligent, new infrastructure concepts must be used for the further development and gradual reconstruction of water infrastructures in order to strengthen resilience and thus also take into account increasing risks such as water scarcity and flood hazards.
- Forward-looking and long-term infrastructure planning must be flexible and take into account the different temporal, spatial and systemic limits of infrastructures and incorporate them into planning, e.g. by increasingly combining green infrastructure with technical / water management infrastructure. In this context, improvements in ecological protection are an important goal.
- The technical and near-natural infrastructures in rural and urban areas play an essential role in enabling water uses and services such as (drinking) water supply and wastewater disposal and treatment in a safe and sustainable manner. With their multifunctionality, the natural systems and near-natural infrastructures are decisively more important for the functioning of water management than the technical infrastructures are at present, if the goals of sustainability are taken into account.

Linking holistic municipal water management with the challenges of multi-crises using multi-level analysis

Cities and municipalities are increasingly confronted with different crises that occur at ever shorter intervals and have ongoing effects over longer periods of time. Whether it is the financial crisis (which is still having an effect), the Corona pandemic, the shortage of skilled workers, the noticeable consequences of local wars (energy and refugee crisis) or municipal over-indebtedness, all crises require attention and generate pressure to act. Although dealing locally with climate change has been part of the tasks of German municipalities for decades (e.g. flood protection due to heavy rainfall), climate change has only been perceived as an acute crisis in real terms since 2022. On the one hand, this was triggered by the extreme damage as a result of the heavy rainfall events in July 2021 (Ahr valley flodding), on the other hand, the dry years in recent past show how much groundwater levels have dropped (and continue to drop), affecting different fields from the water supply to the forestry in Germany.

Regardless of which local, national or global measures are aimed at reducing global warming and are also implemented in a timely manner, the current climate change consequences can only be mitigated in years or decades. Ultimately, it is the municipalities and cities that have to deal with the local consequences and protect their populations. The researchers of the inwa (Institute for Sustainable Water Systems) were repeatedly confronted with these excessive demands, coupled with diffuse fears, in the course of the SPORE project [3] as well as the development of the certificate course "The Way to the Sponge City - Urban Development in Times of Climate Change" [4]. On the part of those responsible for the municipalities, it was often said that the complexity was too high and that they did not know how and where to tackle it. Due to the complexity of the issues and their strong interconnectedness, there is a great fear of making mistakes and wrong decisions. Many of the SPORE project participants or course participants first wished for a way to make this complexity more transparent. In view of these implementation obstacles, the method of multi-level analysis was developed as part of a SPORE sub-project [5] in order to make the different levels and types of complexity visible and, based on this, to identify the different areas of action, define the problem areas and derive necessary measures.

As a result of the multilevel analysis, a "blue-green" upgrading of two pond treatment plants (300 PE and 1000 PE) to a combination of constructed wetlands and downstream trace substance reduction by solar photocatalysis, while maintaining water storage capacities, was recommended for a small German municipality as part of an overall water resource protection strategy. Studies [6] prove the high purification efficiency of this energy-efficient wastewater solution. The retrofitting of, for example, an old fining pond with the so-called free-floating solar photocatalysis also represents a technical innovation, which, without the use of external energy, also succeeds in reducing trace substances in decentralised wastewater systems in rural regions in a cost-saving and effective manner with regard to a desired wastewater reuse.

Due to the efficiency of constructed wetlands, only one wastewater pond is reduced in its storage capacity by changing the system towards a more advanced treatment, the nature-based wastewater infrastructure with a significant water storage capacity is largely preserved. This combination fulfils almost all requirements for a "blue-green" wastewater infrastructure according to the National Water Strategy of the German Parliament. If conventional wastewater technologies were used, the water storage function would be almost completely reduced. Without a supplementary 4th treatment stage, wastewater reuse is also ruled out.

Constructed wetlands achieve efficient elimination of various contaminants through physical, chemical and biological processes using natural and artificial substrates and marsh plants. They increase water quality through a variety of different processes that correspond to those of natural biological systems, with a high buffer capacity and efficient nutrient and heavy metal retention through specially selected filter substrates. Construction, operation and maintenance costs are significantly lower due to the simple system with no essential technical equipment, no external energy input or highly trained operators. Reduction rates of > 90 % for BOD5/COD have been documented [7]. In addition, numerous heavy metals can be safely removed from wastewater (for Pb up to 50 %, for Cd > 90 %, for Fe > 74 %, for Ni > 40 %, for Cr > 89 % and for Cu > 48 %, [8]).

Constructed wetlands are particularly suitable for the selective separation of contaminants and waste in the case of varying inflow volumes. The main advantages are:

- They can be operated with a minimum energy input (only pumping).
- Naturally occurring biocoenoses are responsible in planted soil filters for wastewater treatment, which are more resilient compared to activated sludge and show self-cleaning power.
- They produce much less sludge than activated sludge plants, as only primary sludge is produced in the coarse separation; thus, they do not shift the emission to another medium.
- They are an additional small habitat for various animal species and thus represent an economic and ecological "added value" - fit inconspicuously into the natural environment - provide good

disinfection of the wastewater due to the biological degradation, filter processes and the relatively long residence time in the filter body.
- They are inexpensive to build and operate due to the low level of technical equipment.

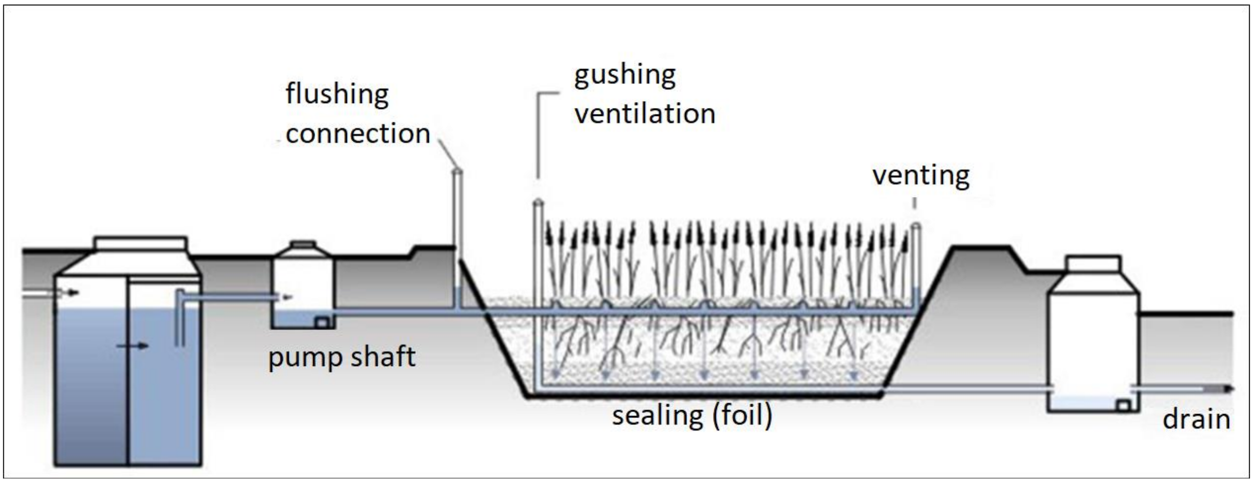

Fig.1. System diagram of constructed wetlands [9]

Research continues to investigate various advanced oxidation processes (AOP) as possible systems for micro pollutant elimination. One possibility is photocatalysis on titanium dioxide, as is being researched and practically tested at Hof University of Applied Sciences [10]. In this process, hydroxyl radicals are generated by charge separation of the photosemiconductor material titanium dioxide. Due to their high oxidation potential, these radicals enable the degradation of most pollutants, theoretically up to CO2 and H2O and mineral salts. The formation of transformation and death-end products, which are a major problem in ozone treatment, is thus reduced. Furthermore, there are no residuals that need further treatment, as is the case with adsorption on activated carbon.

Based on this research on solar photocatalysis, it is recommended for the redevelopment of wastewater ponds to apply this technology in the second pond after a constructed wetland with the aim of wastewater reuse. For this purpose, expanded glass granules with immobilized titanium dioxide layers are placed on the water surface of the selected wastewater ponds. Expanded glass granules are made from regenerated broken glass and can be recycled themselves. Thus, it not only represents a very resource-saving carrier material for photocatalytic coatings, but also expands the range of applications for such coatings due to the property of floatability. Figure 2 shows the general structure of solar photocatalysis.

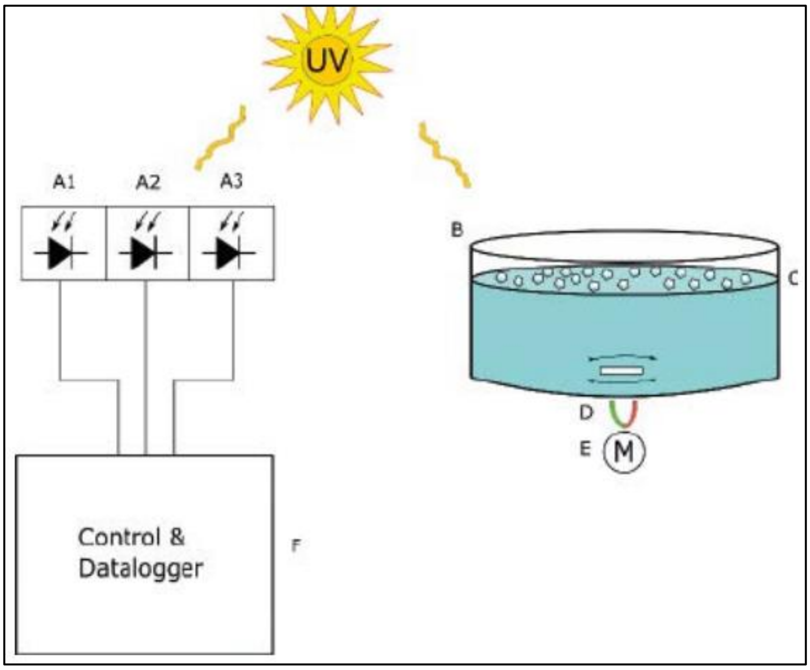

Fig. 2. Principal structure of solar photocatalysis test setup [6]

The previous application-related investigations for the integration of solar photocatalysis show a recommended use for small, decentralized treatment ponds or post-treatment ponds in large wastewater treatment plants. For all reaction kinetics investigated, almost complete micro-pollutant degradation could be achieved with clarification ponds, given moderate solar radiation. Integration with a fining pond could result in 60% total degradation for the micropollutants studied. The use of solar radiation implies a seasonal pattern of achievable removal efficiencies, with performance maxima correlating with periods of low water levels, thus compensating for lower dilution rates. In combination with an upstream constructed wetland, further purification effects can be expected.

Conclusion

The upgrading of old wastewater treatment plants to the presented extended near-natural wastewater solution can be an essential building block in securing water resources for the future. Treated wastewater with a high purification performance in terms of organic and trace substances is a suitable substitute for precious drinking water from endangered groundwater reserves. At the same time, storage capacities integrated into the near-natural wastewater solution can simultaneously serve to mitigate flash flood effects and as water resource storage. With the help of the multi-level analysis, it can be possible to make the importance of a sustainable water resource protection visible in the abundance of crisis-related municipal challenges and to clarify existing synergies with non-water-related infrastructure planning.

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NUMERICAL ASSESSMENT OF LID APPLICATION INFLUENCE ON POLLUTANTS CONCENTRATIONS AND LOADS IN SELECTED URBANIZED INDUSTRIAL CATCHMENT

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The development of urban areas related to the development of their infrastructure leads to an increase in the share of sealed surfaces in relation to permeable surfaces, which directly translates into an increase in the surface runoff stream, in the accumulation of solid pollutants on hardened surfaces, and thus in the concentrations and loads of pollutants transported via storm water sewage to receivers. Pollutants, most often such as: Total Sewage Sludge (TSS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), Total Phosphorus (TP), heavy metals and oil derivatives, transported by storm water and entering the natural surface reservoirs affect their chemical and ecological conditions. Sustainable management of rainwater in the context of climate change and growing anthropogenic pressure on the natural environment is a difficult engineering task.

According with the Water Framework Directive, in many European countries, the alternative methods of managing rain sewage are being developed, allowing retention and purification of storm water at the place of its generation. These assumptions include the use of Low Impact