D Circular water systems

Abstract

Economic growth and human livelihood consume large amounts of water, while also producing wastewater of poor quality. Over extraction of water and discharge of contaminated water affect environments and human livelihood. Even though many water treatment facilities have been implemented worldwide in the past decades, scarcity of clean fresh water is still an aggravating problem. Climate change and contamination by an ever growing number of different types of pollutants are the main causes of this. Continued availability of sufficient and clean water depends on our ability to move away from the current linear practices towards circular practices. Central to this goal is creating clean water cycles in which sufficient water of sufficient quality is available for humans and the environment. WIMEK's research on clean water cycles aims at providing solutions towards circularity by, among others, developing water quality models, sustainable water technologies and urban wastewater reuse strategies. Our research relies on multidisciplinary research methods to develop new integrated concepts on closing water cycles. In addition to scientific impact, we work in close cooperation with stakeholders to ensure that our science leads to solutions for the world's water challenges.

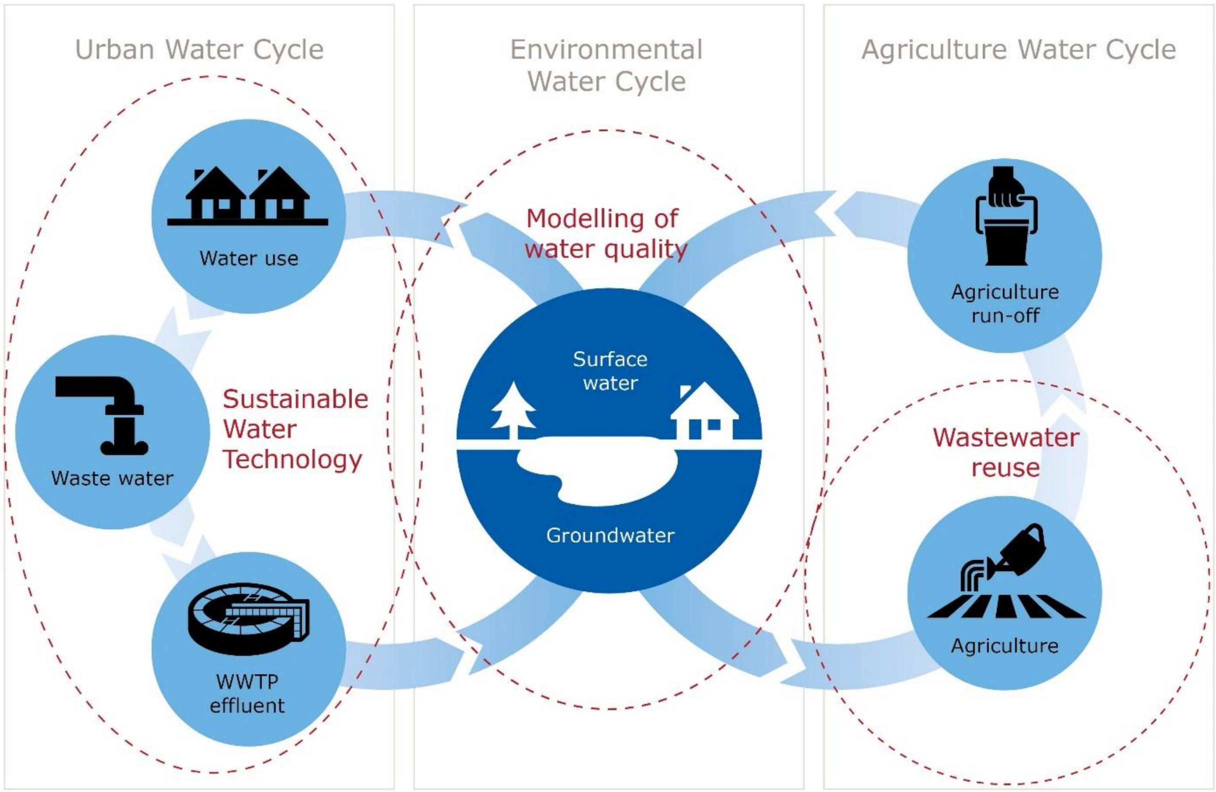

Figure 1 Water links urban areas, the environment, and agriculture. Circular water systems require high quality water to fit urban, environmental and agricultural needs. At WIMEK, we work on ensuring water quality throughout the water cycle. We engineer sustainable water technologies, model water quality, and facilitate wastewater reuse in agriculture. Our research on water quality thus contributes to circular water systems. Illustration by Communication Services, Wageningen University & Research.

Background

Water flows through environmental, agricultural and urban systems, cycling through different usages. While floods and droughts make the news, water quality often ultimately determines actual availability of water resources. Water scarcity stems from a lack of water of sufficient quality for supporting domestic and industrial use, crop production, and aquatic ecosystems. Water quality is affected by anthropogenic activities, resulting in contamination with chemicals, metals, pathogens, plastics, nutrients and salinity. Many water treatment facilities have been implemented worldwide in the past decades, improving water quality at many places. However, in many areas, unsatisfactory wastewater treatment continues to release common pollutants, such as organic waste and nutrients, thus polluting rivers, lakes and coastal areas. Furthermore, worldwide we are challenged by emerging contaminants, including chemicals in consumer products, agroindustry and industry, as well as pathogens and plastic nanoparticles. Our global linear resource approach results in contaminated water unfit for reuse. Water scarcity is further exacerbated by climate change and over extraction, causing salt accumulation and intrusion.

Water contamination affects biodiversity, burdens ecosystem functioning and human health, restricts agricultural and industrial activities, thus carrying high economic costs. Since economic and ecological functioning is increasingly under threat worldwide, circular water system solutions are urgently needed. WIMEK develops innovative approaches to help understand how to create and sustain clean water cycles ensuring that clean water is renewably available for all uses. Therefore, WIMEK links the fields of water management and governance, environmental technology, microbiology, and water quality and aquatic ecology to help to re-establish clean water cycles and ecological, human health and economical functions around the globe.

Research objectives

Below three examples are given on multidisciplinary and transdisciplinary research objectives, linking expertise from different disciplines to create scientific and societal impact.

1. Developing **comprehensive modelling** tools for water quality assessment. Assessment of water quality forms the foundation of our understanding of current and future water quality, at the scale of river basins, lakes and coastal areas. These water quality models build on expertise within WIMEK on water quantity assessments and incorporates evaluation of global change, including climate change, impacts and influence of interventions on the water quality. *This work is led by the WIMEK chair groups WSG and AEW, in collaboration with WRM, among others. Further WUR collaborations exist beyond WIMEK. The work strongly contributes to the newest World Water Quality Assessment[1].*
2. Developing sustainable **water technology**. Water technologies produce clean water for safe discharge into the environment or for reuse in domestic, industrial or agriculture uses. We develop sustainable technologies based on combining fundamental physical, chemical, and biological processes to remove contaminants from water to create water fit for purpose. *Technological innovation is led by the WIMEK chair group ETE, collaborating with other chair groups (MIB, SOC, SLM, WRM, ENP, ENR) and stakeholders (waterboards, technology providers, municipalities).*
3. Developing strategies for **wastewater re-use** in agriculture. Different uses of water demand different water quality standards. We develop context-specific assessments and strategies to match demand and supply, involving upgrading by treatment or mixing water from different sources. *This sustainable development oriented research line is hosted by the WIMEK chair group WRM, collaborating with other chair groups (ETE, ENP).*

Research philosophy

WIMEK performs multidisciplinary research on the environmental, technological, and societal challenges to achieving clean water cycles. **Comprehensive modelling** of water quality forms the foundation for our understanding of current and future water quality. Our focus is mostly on river, lake and coastal water quality, evaluating the recent past and future until ~2100. Comprehensive assessments are required to identify pollution sources and impacts of poor water quality, and to evaluate the effectiveness of interventions, such as implementing technologies. Measuring water quality is essential, but this cannot be done for all water bodies on Planet Earth. Therefore, modelling is an indispensable method to make adequate analyses and predictions, particularly for water scarce areas. Modelling supports an increased understanding of spatially-explicit water quality in data-scarce areas. Moreover, model studies that use scenarios enable evaluation of potential future changes in the water quality and impacts due to changes in socio-economic development, climate change and the implementation of technological or other interventions.

Water technology is one approach to closing water cycles by producing clean water. By treating contaminants, water technologies produce clean water for safe discharge into the environment or fit for reuse in agriculture or drinking water. Developing and implementing water treatment technologies is challenging, as these treatment technologies need to be sustainable, economically feasible, and robust, able to treat varying water quality under different environmental conditions. WIMEK performs research to develop fit-for-purpose water technologies that are used by stakeholders across the globe. Based in a scientific understanding of the mechanisms by which contaminants are removed, our technologies sustainably treat contaminants, ensuring clean water supplies for humans and the environment.

Wastewater reuse potentially provides a reliable strategy to meet increasing demands by water users with different water quality requirements. To match demand and supply, upgrading can be achieved by treatment or mixing of water with varying qualities. An example is the use and management of wastewater for (peri-)urban agriculture in the urbanizing areas of the world. We aim to support safe wastewater re-use in (peri-) urban irrigated agriculture to sustainably provide food to growing urban populations. This is done by studying the practices and politics of wastewater reuse in African and Asian (peri-)urban agriculture. We contribute to a better understanding of effective governance arrangements for small-scale reuse practices and thereby stimulate safe and productive agriculture in urbanizing landscapes across Africa and Asia.

Stakeholder involvement

Together with stakeholders in Uganda we developed a **comprehensive modelling** tool that simulates the number of pathogens that reach the surface water (emissions).[2] The tool provides spatially explicit emissions globally for grids of approximately 50x50 kilometres latitude x longitude and for case studies, such as parishes in Kampala, Uganda. The pathogens can cause disease, such as diarrhoea. Stakeholders, including sanitation safety planners in Kampala, use this tool to prioritise areas for sanitation implementation by evaluating areas with high pathogen emissions. Additionally, they use our tool to evaluate the efficiency of sanitation technology interventions, such as eradicating open defecation, making pit latrines watertight, or improving treatment, in reducing pathogen emissions.

Our **water technology** research is performed in close collaboration with relevant stakeholders, including drinking water companies, water boards, water technology providers, government regulators, industries, farmers and citizens. These stakeholders provide important input on the boundary conditions for new technologies, such as sustainability, treatment efficiencies, or effluent requirements. Our interdisciplinary approach ensures that our technologies are fit-for-use for current demands and future applications. Conducting research on **wastewater reuse** in urbanizing regions is both relevant and challenging since large groups are relying on food production from these systems, while crucial information and knowledge on safe and productive practices is lacking. To explore how best to make water reuse effective in supporting safe and productive irrigated agriculture we team up with local actors (i.e. farmers, public and authority organisations in Bangladesh, Indonesia, Vietnam, African, South American countries) and international organizations such as the International Water Management Institute (IWMI), FAO and the World bank.

Link to education

WIMEK is very active in providing education on water quality, water technology, water microbiology, agricultural water management and water governance. We teach students how to assess water quality by measuring and modelling, develop technologies and design intervention strategies. Several BSc and MSc level courses are available for students in the study programmes Environmental Science, Urban Environmental Management, Earth and Environment, Climate Studies, International Land and Water Management and Biotechnology. At WIMEK we engage in capacity development by supervising students from developing countries and by developing training programs. For example, water quality is a focus within the Copernicus project in which we teach users to develop their own climate and water services. Similarly, we have many sandwich PhD candidates, in which PhDs work part time in Wageningen and their home country to investigate and improve water quality and availability locally.

Research Highlights

Currently, water quality variables, such as nutrients, pathogens, pharmaceuticals, pesticides and plastics are studied individually, although interactions between the variables can be important and interventions for one variable can influence another. We develop **comprehensive** multi-pollutant **models** that uniquely incorporate these interactions to better assess the current and future water quality and potential interventions[3,4]. Nutrient pollution still turns lakes worldwide into toxic soups of algal blooms.

Comprehensive models help to understand the interactions between society and the environment to Develop new solutions to prevent algal blooms in order to restore lakes back to healthy environments[5,6].

We engineer cost effective and **sustainable water technologies** for use in emerging economies and dense urban spaces. Sustainable water technologies are already available for treating classic macro-contaminants (organic matter, phosphate, and nitrogen) present in wastewater. However, implementation of existing technologies is sometimes restricted by limitations in existing infrastructure or local economy. Therefore, we develop technologies that are technically feasible while also recovering economically viable products, such as biogas, nutrients for agriculture, or clean water for irrigation. A notable example is our work on the Vital Urban Filter, where we develop a compact wetland system that treats wastewater for reuse in irrigation while producing ornamental plants with economic value.[7]

Another key challenge is the development of **sustainable technologies** to treat microcontaminants such as micropollutants and pathogens. Clean water cycles are currently threatened by trace concentrations of organic micropollutants, including pharmaceuticals, chemicals in personal care products, pesticides, and hormones as well as pathogens, like antibiotic resistance. These micro-quality parameters form a major hurdle to water reuse in clean and safe water cycles. We perform research to understand the fate and transformation of these contaminants[8], and develop technologies for their removal[9]. We aim to develop technologies that fit market needs for sustainability, affordability, and effective microcontaminant removal. Thus, we design innovative bioreactors and nature-based solutions in combination with advanced physical[10] and chemical[11] techniques.

We explore opportunities for conjunctive use and **wastewater re-use** (surface water, groundwater, treated wastewater) for irrigated agriculture that contribute to increasing health, food security and environmental sustainability. By studying practices along the water chain from upstream users to downstream (re)users, we evaluate how local sociotechnical configurations of water reuse emerge and evolve under influence of both technical and institutional interventions[12,13].

We are active in organising scientific meetings, such as an International Workshop on Global Water Quality Modelling in September 2018 and the Water Science for Impact Conference in October 2018 in which closing water cycles played a major role. These meetings generated scientific outputs, including two special issues in a leading scientific journal[14,15].

Impact

WIMEK is nationally and internationally recognized for its contribution to global efforts to improve water quality and accessibility to clean water. For example, our multi-pollutant modelling and other modelling efforts supports the preliminary World Water Quality Assessment of the United Nations Environment Programme[1]. Our sustainable water technologies are implemented around the world, winning prizes for their innovation and application.[16] For example, WIMEK researchers from ETE currently collaborate with Indian partners on a pilot plant for urban wastewater treatment in New Delhi. Funded jointly by Indian and Dutch governments, the pilot was recently visited by the King and Queen.[17] Our constructed wetland technology is currently piloted at Dow Chemical in Terneuzen[18], where we treat industrial wastewater for reuse at the DOW Chemical plant.

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