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Report

The United Nations World Water Development Report 2017

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The United Nations World Water Development Report 2017

WASTEWATER

THE UNTAPPED RESOURCE

Published in 2017 by the United Nations Educational, Scientific and Cultural Organization,
7, place de Fontenoy, 75352 Paris 07 SP, France

This report is published by UNESCO on behalf of UN-Water. The list of UN-Water Members and Partners are available on: www.unwater.org

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ISBN 978-92-3-100201-4

Suggested citation:
WWAP (United Nations World Water Assessment Programme). 2017. *The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource*. Paris, UNESCO.

The ideas and opinions expressed in this publication are those of the authors; they are not necessarily those of UNESCO and do not commit the Organization. The contents were contributed by the UN-Water Members and Partners listed on the title pages of the chapters therein. UNESCO and the United Nations World Water Assessment Programme (WWAP) are not responsible for errors in the content provided or for discrepancies in data and content between contributed chapters.

WWAP provided the opportunity for individuals to be listed as authors and contributors or to be acknowledged in this publication. WWAP is not responsible for any omissions in this regard.

Original cover design by Phoenix Design Aid

Printed by UNESCO CLD

This publication is printed in vegetable inks on FSC Mixed Sources paper, supporting responsible use of forest reserves, 100% recycled, acid-free and chlorine-free.

Printed in France

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FOREWORD

by **Irina Bokova**
Director-General of UNESCO

In a world where demands for freshwater are ever growing, and where limited water resources are increasingly stressed by over-abstraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable.

This is how the *2017 World Water Development Report* concludes, highlighting the vital importance of improving the management of wastewater for our common future.

Continuing 'business as usual' means allowing overwhelming neglect to worsen. It is estimated that well over 80 per cent of wastewater worldwide (over 95 per cent in some developing countries) is released into the environment without treatment. The consequences are alarming. Water pollution is worsening in most rivers across Africa, Asia and Latin America. In 2012, over 800,000 deaths worldwide were caused by contaminated drinking water, inadequate handwashing facilities and inappropriate sanitation services. In the seas and ocean, de-oxygenated dead zones caused by the discharge of untreated wastewater are growing rapidly, affecting an estimated 245,000 km^2 of marine ecosystems, impacting on fisheries, livelihoods and food chains.

When not ignored, used water has long been seen as simply a burden for disposal. With rising water scarcity in many regions, this is changing, and we see increasing recognition of the importance of wastewater collection, treatment and reuse. Infrastructure is a central issue in all countries. Data availability remains a persisting challenge, particularly in developing countries. Recent analysis shows that out of 181 countries, only 55 had information on the generation, treatment and use of wastewater, and the remaining ones had no or only partial data. In the majority of countries where data were available, it was outdated. This information bottleneck impedes the research and development necessary to craft innovative technologies and adapt existing ones to local specificities and needs.

The 2017 *World Water Development Report* shows that improved wastewater management is as much about reducing pollution at the source, as removing contaminants from wastewater flows, reusing reclaimed water and recovering useful by-products. Together, these four actions generate social, environmental and economic benefits for all society, contributing to overall well-being and health, water and food security, and sustainable development. The cross-cutting importance of wastewater is highlighted in the 2030 Agenda for Sustainable Development, through Sustainable Development Goal 6 on water and sanitation, and especially Target 6.3 on halving the proportion of untreated wastewater and substantially increasing recycling, and safe reuse globally.

Raising social acceptance of the use of wastewater is essential to moving forward. This is the importance of education and training, and new forms of awareness-raising, to change perceptions of health risks and address socio-cultural concerns, to bolster public acceptance.

This is also good business. As an essential component of a circular economy, wastewater use and by-product recovery can generate new business opportunities and help to recover the costs of new, innovative and adapted installations, allowing us to recover energy, nutrients, metals and other by-products.

For its part, UNESCO, through its 'water family,' is working to support Member States in responding to water quality challenges – including the World Water Assessment Programme of UNESCO, the International Hydrological Programme, the UNESCO-IHE Institute for Water Education in Delft, and numerous Category II Centres and Chairs around the world. Our action stretches across the board, from promoting scientific research, mobilizing and disseminating knowledge, and facilitating the exchange of technological and policy approaches to building capacity and raising awareness on risks caused by emerging pollutants in water and wastewater.

As always, the 2017 Report is the result of partnership across the United Nations system and among the 31 members of UN-Water, for which I am deeply grateful. I wish to thank the Government of Italy for its support to the Secretariat of the World Water Assessment Programme, to ensure its long-term sustainability and productivity. In this spirit, I invite all to take ownership over this Report and its conclusions, to raise the flag for new, just and sustainable approaches to water as a driver for a better future for all.

Irina Bokova

Irina Bokova

FOREWORD

by **Guy Ryder**
Chair of UN-Water and Director-General of International Labour Organization

In the fifth century BC, Heraclitus is quoted as saying "change is the only constant in life." Today, this holds true more than ever. As populations and urban settlements grow, so do our demands; transforming our societies and planet before our eyes.

The 2017 edition of the United Nations World Water Development Report (WWDR) explores the issue of wastewater and its potential as a sustainable resource. However, the findings show how much work we have to do: "Worldwide, the vast majority of wastewater is neither collected nor treated. Furthermore, wastewater collection per se is not synonymous with wastewater treatment. In many cases, collected wastewater is merely discharged directly into the environment without any treatment. Agricultural runoff is almost never collected or treated, so that metrics for these types of wastewater flows are practically non-existent."

Of course, as well as being a squandered opportunity, releasing most wastewater back into the ecosystem without being treated is having deep impacts on human health and the natural world.

The 2017 edition of the WWDR, the flagship publication of UN-Water, conveys to readers that wastewater has long been a neglected resource – it is not only a solution to address growing water scarcity but also a rich source of nutrients, minerals and energy, all of which can be cost-efficiently extracted. Expanding on the 2015 UN-Water Analytical Brief on Wastewater Management, the WWDR also discusses the circular economy, innovation and many regional aspects.

The report clearly reflects the consensus among 31 Members and 38 Partners of UN-Water that issues related to wastewater extend beyond Sustainable Development Goal 6 and its wastewater target and cuts across many SDG targets.

I would like to thank all my UN-Water colleagues for their contributions, including UNESCO and its World Water Assessment Programme for coordinating the production of this high-quality report, which could have such far-reaching ramifications for progress across the Sustainable Development Goals.

Guy Ryder

Guy Ryder

PREFACE

by **Stefan Uhlenbrook**, WWAP Coordinator
and **Richard Connor**, Editor-in-Chief

The 2017 edition of the United Nations World Water Development Report (WWDR), the fourth in a series of annual, theme-oriented reports, addresses an often overlooked issue that is critical to water resources management and the provision of basic water-related services: wastewater.

Wastewater is not merely a water management issue – it affects the environment and all living beings, and can have direct impacts on economies, both mature and emerging. Furthermore, wastewater flows contain a number of useful materials, such as nutrients, metals and organic material that, much like the water itself, can be extracted and used to for other productive purposes. As such, wastewater constitutes a valuable resource that, if sustainably managed, is set to become a central pillar of the circular economy. The upside to improving the way we manage wastewater is huge, with potential co-benefits to societies and the environment.

The entire notion of wastewater is itself somewhat of an oxymoron. Once water has been used for any purpose, it should not be seen as 'wasted'. In other languages it is called 'used water' (*eaux usées* in French), 'residual water' (*aguas residuales* in Spanish) or 'after-use water' (*Abwasser* in German). Indeed, making the case for moving away from the notion that used water is a waste to be disposed of – towards wastewater as a resource – is the central message of this report.

In preparing the WWDR 2017, we quickly became aware of the wide variety of definitions of wastewater, which can mean many different things to different people. Engineers, urban planners, environmental managers and academics, not to mention several fellow UN Agencies, have addressed various aspects of wastewater in numerous reports, each offering their own insightful perspectives and vocabularies. We have endeavoured to draw upon many of these documents – as evidenced by the sheer length of the reference list – to present a balanced, fact-based and neutral account of the current wealth of knowledge, covering the most recent developments pertaining to wastewater management, and the various benefits and opportunities it offers in the context of a circular economy.

Improved wastewater management will be critical for green growth, especially in the context of the 2030 Agenda for Sustainable Development. Target 6.3 of the Sustainable Development Goals (SDGs) explicitly focuses on reducing pollution and improving the disposal, management and treatment of wastewater and its impact on ambient water quality. This target is highly relevant to achieving several other SDGs.

Maximizing wastewater's potential as a valuable and sustainable resource will require creating an enabling environment for change, including suitable legal and regulatory frameworks, appropriate financing mechanisms and social acceptance. We remain confident that, with the political will to do so, current obstacles, such as the lack of knowledge, capacity, data and information about wastewater, can be quickly and effectively overcome.

Although primarily targeted at national-level decision-makers and water resources managers, we hope that this report will also be of interest to the broader developmental community, academics and anyone interested in building an equitable and sustainable future for all.

This latest edition of the WWDR is the result of a concerted effort between FAO, UNDP, UNECE, UNEP, UNESCAP, UNESCO, UNESCWA, UN-Habitat, UNIDO and WWAP. Furthermore, the report benefited from the inputs and contributions of several UN-Water members and partners, members of WWAP's Technical Advisory Committee, as well as from dozens of scientists, professionals and NGOs who provided a wide range of relevant material. The report has been gender-mainstreamed similar to the earlier editions.

On behalf of the WWAP Secretariat, we would like to extend our deepest appreciation to the afore-mentioned agencies, members and partners of UN-Water, and to the writers, editors and other contributors for collectively producing this unique and authoritative report that will, hopefully, have multiple impacts worldwide.

We are profoundly grateful to the Italian Government for funding the Programme and to the Regione Umbria for hosting the WWAP Secretariat in Villa La Colombella in Perugia. Their contributions have been instrumental to the production of the WWDR.

Our special thanks go to Ms Irina Bokova, Director General of UNESCO, for her vital support to WWAP and the production of the WWDR. The guidance of Mr Guy Ryder, Director-General of the International Labour Organization, as Chair of UN-Water, has made this publication possible.

Last but not least, we extend our most sincere gratitude to all our colleagues at the WWAP Secretariat, whose names are listed in the acknowledgments. The report could not have been completed without their dedication and professionalism, especially in light of the challenges and difficulties related to the 2016 earthquakes in Umbria and the surrounding regions of Italy.

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ACKNOWLEDGEMENTS

The United Nations World Water Assessment Programme (WWAP) recognizes the valuable contributions of FAO, UNDP, UNECE, UNEP, UNESCAP, UNESCO, UNESCWA, UN Habitat and UNIDO whose inputs as chapter lead agencies made the content preparation of this report possible. We also would like to thank those UN-Water members and partners, all the organizations, institutions and individuals, who provided useful inputs and comments during multiple rounds of review.

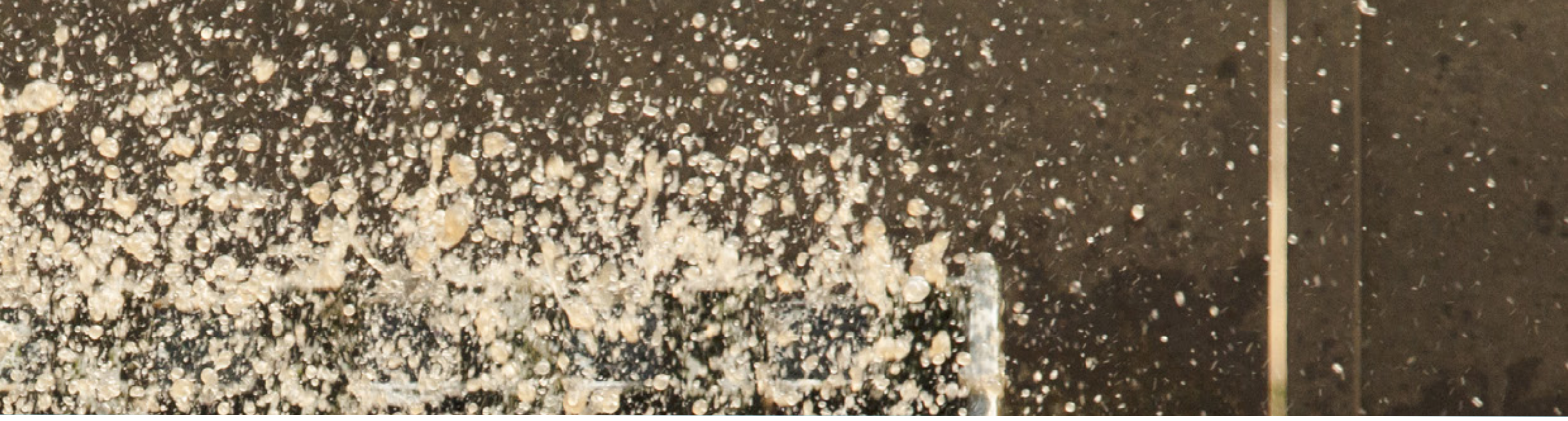
The WWDR 2017 benefitted from the reviews, comments and guidance of WWAP's Technical Advisory Committee.

We wish to express our earnest thanks to Irina Bokova, Director-General of UNESCO, whose support was instrumental in preparing the report. Flavia Schlegel, Assistant Director General of UNESCO for Natural Sciences, Blanca Jiménez-Cisneros, Director of the Division of Water Sciences and Secretary of the International Hydrological Programme (IHP), and colleagues at IHP deserve special recognition for their valuable encouragement and assistance.

We greatly appreciate the generous help extended to us by the UNESCO Field Offices in Almaty, Beijing, Brasilia, Cairo and New Delhi for the translation of the Executive Summary into Russian, Chinese, Portuguese, Arabic and Hindi languages, respectively. The German translation was made possible, thanks to the German Commission for UNESCO.

WWAP is grateful for the generous financial contribution of the Italian Government, and for the facilities provided by Regione Umbria. The report is also financially supported by the Norwegian Ministry of Foreign Affairs.

Wastewater treatment plant



EXECUTIVE SUMMARY

Most human activities that use water produce wastewater. As the overall demand for water grows, the quantity of wastewater produced and its overall pollution load are continuously increasing worldwide.

In all but the most highly developed countries, the vast majority of wastewater is released directly to the environment without adequate treatment, with detrimental impacts on human health, economic productivity, the quality of ambient freshwater resources, and ecosystems.

Although wastewater is a critical component of the water management cycle, *water* after it has been used is all too often seen as a burden to be disposed of or a nuisance to be ignored. The results of this neglect are now obvious. The immediate impacts, including the degradation of aquatic ecosystems and waterborne illness from contaminated freshwater supplies, have far-reaching implications on the well-being of communities and peoples' livelihoods. Continued failure to address wastewater as a major social and environmental problem would compromise other efforts towards achieving the 2030 Agenda for Sustainable Development.

In the face of ever-growing demand, wastewater is gaining momentum as a reliable alternative source of water, shifting the paradigm of wastewater management from 'treatment and disposal' to 'reuse, recycle and resource recovery'. In this sense, wastewater is no longer seen as a problem in need of a solution, rather it is part of the solution to challenges that societies are facing today.

Wastewater can also be a cost-efficient and sustainable source of energy, nutrients, organic matter and other useful by-products. The potential benefits of extracting such resources from wastewater go well beyond human and environmental health, with implications on food and energy security as well as climate change mitigation. In the context of a circular economy, whereby economic development is balanced with the protection of natural resources and environmental sustainability, wastewater represents a widely available and valuable resource.

The outlook is undeniably optimistic, provided action is taken now.

The world's water: Availability and quality

Globally, water demand is predicted to increase significantly over the coming decades. In addition to the agricultural sector, which is responsible for 70% of water abstractions worldwide, large increases in water demand are predicted for industry and energy production. Accelerated urbanization and the expansion of municipal water supply and sanitation systems also contribute to the rising demand.

Climate change scenarios project an exacerbation of the spatial and temporal variations of water cycle dynamics, such that discrepancies between water supply and demand are becoming increasingly aggravated. The frequency and severity of floods and droughts will likely change in many river basins worldwide. Droughts can have very significant socio-economic and environmental consequences. The crisis in Syria was, among other factors, triggered by a historic drought (2007–2010).

Two thirds of the world's population currently live in areas that experience water scarcity for at least one month a year. About 500 million people live in areas where water consumption exceeds the locally renewable water resources by a factor of two. Highly vulnerable areas, where non-renewable resources (i.e. fossil groundwater) continue to decrease, have become highly dependent on transfers from areas with abundant water and are actively seeking affordable alternative sources.

The availability of water resources is also intrinsically linked to water quality, as the pollution of water sources may prohibit different type of uses. Increased discharges of untreated sewage, combined with agricultural runoff and inadequately treated wastewater from industry, have resulted in the degradation of water quality around the world. If current trends persist, water quality will continue to degrade over the coming decades, particularly in resource-poor countries in dry areas, further endangering human health and ecosystems, contributing to water scarcity and constraining sustainable economic development.

Wastewater: Global trends

On average, high-income countries treat about 70% of the municipal and industrial wastewater they generate. That ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% undergoes treatment of any kind. These estimates support the often-cited approximation that, globally, over 80% of all wastewater is discharged without treatment.

In high-income countries, the motivation for advanced wastewater treatment is either to maintain environmental quality, or to provide an alternative water source when coping with water scarcity. However, the release of untreated wastewater remains common practice, especially in developing countries, due to lacking infrastructure, technical and institutional capacity, and financing.

Wastewater, sanitation and the sustainable development agenda

Access to improved sanitation services can contribute significantly to the reduction of health risks. Further health gains may be realized through improved wastewater treatment. While 2.1 billion people gained access to improved sanitation facilities since 1990, 2.4 billion still do not have access to improved sanitation and nearly 1 billion people worldwide still practice open defecation.

However, improved sanitation coverage does not necessarily equate with improved wastewater management or public safety. Only 26% of urban and 34% of rural sanitation and wastewater services effectively prevent human contact with excreta along the entire sanitation chain and can therefore be considered safely managed.

Building on the experience of the MDGs, the *2030 Agenda for Sustainable Development* has a more comprehensive goal for water, going beyond the issues of water supply and sanitation. SDG Target 6.3 states: *By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*. The extremely low level of wastewater treatment reveals an urgent need for technological upgrades and safe water reuse options to support the achievement of Target 6.3, which is critical for achieving the entire Agenda. The efforts required to achieve this Target will place a higher financial burden on low-income and lower middle-income countries, putting them at an economic disadvantage compared to high-income and upper middle-income countries.

Governance challenges

The benefits to society of managing human waste are considerable, for public health as well as for the environment. For every US$1 spent on sanitation, the estimated return to society is US$5.5.

Overcoming the practical difficulties of implementing water quality regulations can be particularly challenging. In order to realize the goals of water quality improvement and water resources protection, individuals and organizations responsible for various aspects of wastewater management need to comply and act in the collective interest. Benefits are only realized once everyone abides by the rules to protect water resources from pollution.

Involving citizens in decision-making at all levels promotes engagement and ownership. This includes decisions as to what types of sanitation facilities are desirable and acceptable, and how they can be securely funded and maintained over the long term. It is especially important to reach out to marginalized groups, ethnic minorities and people living in extreme poverty, in remote rural areas or in informal urban settlements. It is also essential to engage with women, as they bear the brunt of the health consequences stemming from the unsafe management of human waste.

Technical aspects of the wastewater management cycle

Wastewater is roughly composed of 99% water and 1% suspended, colloidal and dissolved solids.

The consequences of releasing untreated or inadequately treated wastewater can be classified into three groups: i) harmful effects on human health; ii) negative environmental impacts; and iii) adverse repercussions on economic activities.

Controlling and regulating various wastewater flows is the ultimate purpose of wastewater management. The wastewater management cycle can be broken down into four basic interconnected phases:

1. Prevention or reduction of pollution at the source

Approaches to water pollution control that focus on wastewater prevention and minimization should be given priority over traditional end-of-pipe treatment whenever possible. These approaches include prohibiting or controlling the use of certain contaminants to eliminate or limit their entering into wastewater streams through regulatory, technical and/or other means. Remedial actions to clean up polluted sites and water bodies are generally much more expensive than measures to prevent pollution from occurring.

Monitoring and reporting of pollutant discharges to the environment and ambient water quality are necessary to achieve progress. If something is not measured, the problem cannot be defined and the effectiveness of policies cannot be assessed.

2. Wastewater collection and treatment

Centralized waterborne waste disposal remains the prevalent method for sanitation and for evacuating wastewater from domestic, commercial and industrial sources. Globally, about 60% of people are connected to a sewer system (although only a small proportion of the collected sewerage is actually treated). Other sanitation options, such as on-site systems, are well-suited to rural areas and low population density settings, but can be expensive and difficult to manage in dense urban environments.

Large-scale centralized wastewater treatment systems may no longer be the most viable option for urban water management in many countries. Decentralized wastewater treatment systems, serving individual or small groups of properties, have shown an increasing trend worldwide. They allow for the recovery of nutrients and energy, save freshwater and help secure access to water in times of scarcity. It has been estimated that the investment costs for these treatment facilities represent only 20–50% of conventional treatment plants, with even lower operation and maintenance costs (in the range of 5–25% of conventional activated sludge treatment plants).

Low-cost sewerage systems have become a method of choice for neighbourhoods of all income levels. They differ from those used in conventional sewer design and focus on the concept that solid-free sewage is conveyed in the system. These systems lend themselves to community management and are very well-suited to extend and expand existing systems or to connect satellite communities to centralized systems. They have also been used in refugee settings. One drawback is that they are not suitable for stormwater drainage.

Ecosystems can be effective in terms of providing economical wastewater treatment services, provided that these ecosystems are healthy, the pollutant load (and types of contaminants) in the effluent is regulated and the ecosystem’s pollution assimilation capacity is not exceeded.

3. Using wastewater as an alternative source of water

The use of untreated or diluted wastewater for irrigation has taken place for centuries. Reclaimed water also offers opportunities for a sustainable and reliable water supply for industries and municipalities, especially with a growing number of cities relying on more distant and/or alternative sources of water to meet increasing demand.

In general, water reuse becomes more economically feasible if the point of reuse is close to the point of production. Treating wastewater to a water quality standard acceptable by a user (i.e. 'fit-for-purpose' treatment) increases the potential for cost recovery. Wastewater use becomes all the more competitive when freshwater prices also reflect the opportunity cost of using freshwater and pollution charges reflect the cost of removing pollutants from wastewater flows.

The planned use of treated and partially treated wastewater for ecosystem services can increase resource efficiency and provide benefits to ecosystems through reducing freshwater abstractions, recycling and reusing nutrients, allowing fisheries and other aquatic ecosystems to thrive by minimizing water pollution, and recharging depleted aquifers.

4. The recovery of useful by-products

Wastewater's vast potential as a source of resources, such as energy and nutrients, remains underexploited.

Energy can be recovered in the form of biogas, heating/cooling and electricity generation. Technologies exist for on-site energy recovery through sludge/biosolids treatment processes integrated in wastewater treatment plants, allowing them to transition from major energy consumers to energy neutrality, or even to net energy producers. Energy recovery can also help facilities reduce operational costs and their carbon footprint, enabling increased revenue streams through carbon credits and carbon trading programmes. There are also opportunities for combined energy and nutrient recovery. Off-site energy recovery involves sludge incineration in centralized plants through thermal treatment processes.

The development of technologies for recovering nitrogen and phosphorus from sewage or sewage sludge is advancing. Phosphorus recovery from on-site treatment facilities such as septic tanks and latrines can be technically and financially feasible by transforming septage into organic or organic-mineral fertilizer. Moreover, faecal sludge presents a relatively lower risk of chemical contamination compared to sewerage biosolids.

It is likely that urine collection and use will become an increasingly important component of ecological wastewater management, as it contains 88% of the nitrogen and 66% of the phosphorus found in human waste – essential components for plant growth. With extractable mineral phosphorus resources predicted to become scarce or even exhausted over the next decades, its recovery from wastewater offers a realistic and viable alternative.

Municipal and urban wastewater

The composition of municipal wastewater can vary considerably, reflecting the range of contaminants released by various domestic, industrial, commercial and institutional sources. Wastewater from domestic sources is usually relatively free of hazardous substances, but there are growing concerns about emerging pollutants including commonly used medications that, even at low concentrations, may have long-term impacts.

Accelerated urban growth poses several challenges, including dramatic increases in the generation of municipal wastewater. However, this growth also offers opportunities to break away from the past (inadequate) water management practices and adopt innovative approaches, which include the use of treated wastewater and by-products.

Wastewater generation is one of the biggest challenges associated to the growth of informal settlements (slums) in the developing world. There were more slum dwellers in 2012 than in 2000, a trend that will likely continue in the future. Slum dwellers frequently have to rely on unsewered communal toilets, use open spaces or dispose of faeces in polythene bags (i.e. flying toilets). Communal toilets are not widely used, due to a lack of water, poor maintenance, and the cost to the user. Finding a suitable place to go to the toilet is especially problematic for women, causing risks related to personal security, embarrassment and hygiene.

Industry

The toxicity, mobility and loading of industrial pollutants have potentially more significant impacts on water resources, human health and the environment than actual volumes of wastewater. The first step is to keep the volumes and toxicity of pollution to a minimum at the point of origin, from concept to design and in operations and maintenance. This includes substitution with more environmentally friendly raw materials and biodegradable process chemicals, as well as staff education and training to address pollution-related issues. The second step is to recycle as much water as possible within a plant, thus minimizing discharge.

Small- and medium-sized enterprises (SMEs) and informal industries often discharge their wastewater into municipal systems or directly into the environment. Industries discharging into municipal systems or surface water have to meet discharge regulations to avoid fines, so in many cases end-of-pipe treatment is required at the plant before release. In some situations, however, industries may find it more economical to pay fines than to invest in treatment to meet regulations.

One notable opportunity for industrial wastewater use and recycling is the cooperation between plants through industrial symbiosis. This is best seen in eco-industrial parks that locate industries adjacent to one another in such a way as to take advantage of various wastewater flows and water and by-product recycling. For SMEs, this can be a significant way to save on wastewater treatment costs.

Agriculture

Over the past half century, the area equipped for irrigation has more than doubled, total livestock has more than tripled and inland aquaculture has grown more than twentyfold.

Water pollution from agriculture occurs when fertilizers (nutrients) and other agrochemicals are applied more heavily than crops can absorb them or when they are washed away. Efficient irrigation schemes can greatly reduce both water and fertilizer loss. Nutrients can also be released by livestock production and aquaculture.

Agriculture can be a source of several other types of pollutants, including organic matter, pathogens, metals and emerging pollutants. Over the last 20 years, new agricultural pollutants have emerged, such as antibiotics, vaccines, growth promoters and hormones that may be released from livestock and aquaculture farms.

If adequately treated and safely applied, domestic wastewater is a valuable source of both water and nutrients. In addition to enhancing food security, water reuse for agriculture can have significant health benefits, including improved nutrition. The use of municipal wastewater is a common pattern in countries of the Middle East and North Africa, Australia, and the Mediterranean, as well as in China, Mexico and the USA. The practice has been most successful in urban and peri-urban areas, where wastewater is easily available, generally free of charge, and where there is a market for agricultural products.

Regional perspectives

One of the main challenges related to wastewater in Africa is the overall lack of infrastructure for collection and treatment, which results in the pollution of often-limited surface and groundwater resources. African cities are growing quickly, and their current water management systems cannot keep up with the growing demand. However, this situation provides opportunities from improved urban wastewater management using multi-purpose technologies for water reuse and the recovery of useful by-products. Strong advocacy is needed to convince policy-makers of the phenomenal 'cost of inaction' in terms of socio-economic development, environmental quality and human health.

The use of safely treated wastewater has become a means of increasing water availability in several Arab states and has been included as a core component of water resources management plans. In 2013, 71% of the wastewater collected in Arab States was safely treated, of which 21% is being used, mostly for irrigation and groundwater recharge. Integrated water resources management and nexus approaches that consider the linkages between water, energy, food and climate change provide a framework for considering avenues for supporting the improved collection, transfer, treatment and use of wastewater in the Arab region from a water security perspective.

By-products from domestic wastewater, such as salt, nitrogen and phosphorus, have potential economic value that can be used to improve livelihoods in the Asia-Pacific region. Case studies in South-East Asia have shown that revenues from wastewater by-products, such as fertilizer, are significantly higher than the operational costs of wastewater systems that harvest by-products, providing evidence that resource recovery from wastewater is a viable and profit-producing business model. More needs to be done across the region to support municipal and local governments in managing urban wastewater and capturing its resource benefits.

The level of access to improved sanitation across the European and North American region is relatively high (95%) and wastewater treatment levels have improved during the last 15–20 years. Although tertiary treatment has increased gradually, significant volumes of wastewater are still collected and discharged without treatment, particularly in Eastern Europe. Demographic and economic changes have rendered the effectiveness of some of the larger centralized systems suboptimal, as exemplified by several oversized and maladapted systems in parts of the former Soviet Union. Cities throughout the region are facing the financial burden associated with repairing or replacing ageing infrastructure.

The coverage of urban wastewater treatment in Latin America and the Caribbean has almost doubled since the late 1990s and is now estimated to have reached between 20% and 30% of the wastewater collected in urban sewerage systems. This improvement is mainly attributed to increasing levels of water and sanitation coverage, the improved financial situation of many service providers (which in recent years have made important advances towards cost recovery), and strong socio-economic growth in the region over the past decade. A further contributing factor was the integration of regional economies into global markets. Treated wastewater could be an important source of water supply in some cities, particularly those located in arid areas (e.g. Lima) or where long-distance transfers are required to meet growing demands, particularly during drought (e.g. São Paulo).

Creating an enabling environment for change

Improved wastewater treatment, the increase in water reuse and the recovery of useful by-products support the transition to a circular economy by helping reduce water withdrawals and the loss of resources in production systems and economic activities.

Suitable legal and regulatory frameworks

An effective regulatory framework requires that the implementing authority has the necessary technical and managerial capacity and performs in an independent fashion, with sufficient powers to enforce rules and guidelines. Transparency and access to information motivates compliance by promoting trust among users with respect to the implementation and enforcement processes. Achieving progress will require a flexible and incremental approach.

Policies and regulatory instruments are implemented locally and need to be adapted to varied circumstances. It is therefore important that political, institutional and financial support be given to ‘bottom-up’ initiatives and small-scale local (i.e. decentralized) provision of wastewater management services.

New regulations regarding water reuse and the recovery of wastewater by-products are also required. There is often little or no legislation on quality standards for these products, creating market uncertainties that can discourage investment. Markets for these products could be stimulated by financial or legal incentives (e.g. compulsory blending of recovered phosphates in artificial fertilizer).

Cost recovery and appropriate financing mechanisms

Wastewater management and sanitation are generally considered to be expensive and capital-intensive. This is especially the case of large centralized systems, which require a large degree of up-front capital expenditure and relatively high operation and maintenance costs over the medium and long term to avoid rapid deterioration. The problem is further exacerbated by chronically lacking investment in the development of institutional and human capacity. However, the costs of inadequate investment in wastewater management are far greater, particularly when the direct and indirect damages to health, socio-economic development and the environment are taken into consideration.

Decentralized wastewater treatment systems can be used to offset some financial problems generated by centralized systems. When properly designed and implemented, such low-cost technologies can provide satisfactory results in terms of effluent quality, although they too require an appropriate level of operation and maintenance in order to avoid system failure.

Wastewater use can add new revenue streams to wastewater treatment, particularly under conditions of recurring or chronic water scarcity. Several different business models have been implemented where cost and value recovery offer a significant advantage from a financial perspective. However, revenues from the sale of treated wastewater alone are not generally adequate to cover the operational and maintenance costs of the water treatment facility itself. The recovery of nutrients (mainly phosphorus and nitrogen) and energy can add significant new value streams to improve the proposition of cost recovery.

Although revenues from wastewater use and resource recovery may not always cover their extra costs, the benefits from investments in water reuse may compare well with the cost of dams, desalination, inter-basin transfers, and other options to increase water availability.

Even when delivered to the tap, potable water remains generally undervalued and underpriced when compared to the total cost of the service. Treated wastewater must itself be priced lower than potable water in order to gain public acceptance. Pricing water from all sources to better reflect its actual cost enables investments that can translate into affordable service delivery to all members of society, including the poor.

Minimizing risks to people and the environment

The discharge of untreated wastewater can have severe impacts on human and environmental health, including outbreaks of food-, water- and vector-borne diseases, as well as pollution and the loss of biological diversity and ecosystem services. Exposure of vulnerable groups, especially women and children, to partially treated or untreated wastewater requires specific attention. Limited awareness of health risks associated with wastewater use, due to poverty and low education, further contributes to these risks, in particular in developing countries. Whenever human exposure is considered likely (i.e. via food or direct contact), more rigorous risk management measures are required.

Building knowledge and capacity

Data and information on wastewater generation, treatment and use is essential for policy-makers, researchers, practitioners and public institutions in order to develop national and local action plans aimed at environmental protection and the safe and productive use of wastewater. Knowledge concerning the volumes and, perhaps even more importantly, the constituents of wastewater are necessary tools for protecting human and environmental health and safety. However, there is a pervasive lack of data relating to virtually all aspects of water quality and wastewater management, particularly in developing countries.

Appropriate and affordable technologies, both new and well-established, need to be transferred from developed to developing countries. Research is needed to improve the understanding of the dynamics of emerging pollutants and improve methods to remove these pollutants from wastewater. It is also essential to understand how external factors like climate change will impact wastewater management.

In order to enhance wastewater management, it is essential to ensure that the appropriate levels of human capacity are in place. Organizational and institutional capacity in the wastewater management sector is often lacking and, therefore, any investment – large-scale centralized wastewater management systems or smaller, on-site systems – is at stake.

Public awareness and social acceptance

Even if wastewater use projects are technically well-designed, appear financially realizable, and have incorporated appropriate safety measures, water reuse schemes can fail if planners do not adequately account for the dynamics of social acceptance. Generally, the use of wastewater encounters strong public resistance due to a lack of awareness and trust with regard to human health risks. Awareness raising and education are the main tools to overcome social, cultural and consumer barriers. Such awareness campaigns need to be tailored to consumers with different cultural and religious backgrounds.

The health risks associated with water reuse need to be assessed, managed, monitored and reported on a regular basis in order to gain public acceptance and to maximize the benefits of using wastewater while minimizing the negative impacts. In the case of drinking water (i.e. potable water reuse), extensive information campaigns are required to build trust in the system and overcome the so-called ‘yuck’ factor.

Coda

In a world where demands for freshwater are continuously growing, and where limited water resources are increasingly stressed by over-abstraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable in the context of a circular economy.

PROLOGUE

WWAP | Stefan Uhlenbrook, Angela Renata Cordeiro Ortigara and Richard Connor
With contributions from: Sara Marjani Zadeh (FAO)

STATE OF WATER RESOURCES: AVAILABILITY AND QUALITY

Collecting water from a river in Bor (South Sudan)

The Prologue provides a brief overview of two core aspects of the state of the world's water resources that are directly related to wastewater: water availability and ambient water quality. While adequately treated wastewater is a resource that can be used to address water supply shortages, the level of wastewater treatment directly affects ambient water quality, with implications on water availability. The external drivers that will dictate future trends in water availability and quality are described, with a special focus on demographic dynamics and climate change.

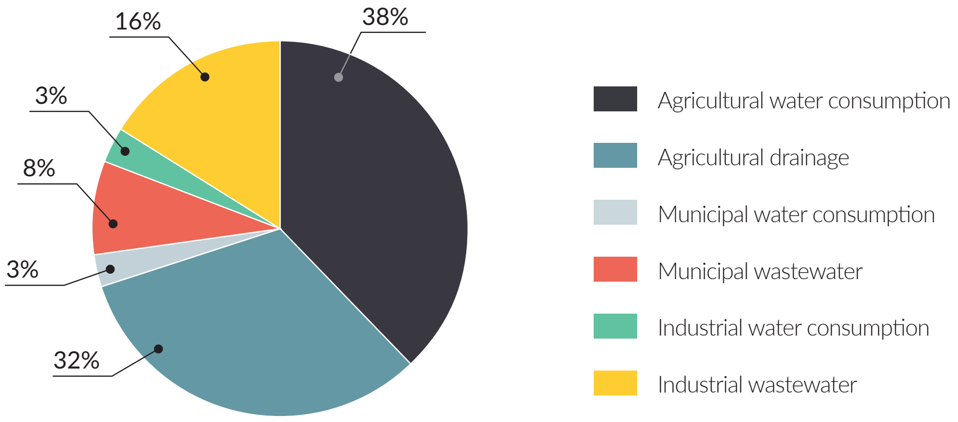
Global wastewater production and treatment

Although data on wastewater generation, collection and treatment is grossly lacking, it is clear that, worldwide, the vast majority of wastewater is neither collected nor treated. Furthermore, wastewater collection per se is not synonymous with wastewater treatment. In many cases, collected wastewater is merely discharged directly into the environment without any treatment. Agricultural runoff is almost never collected or treated, so that metrics for these types of wastewater flows are practically non-existent.

The AQUASTAT database of the Food and Agriculture Organization of the United Nations (FAO) estimates global freshwater withdrawals at 3,928 km^3 per year. An estimated 44% (1,716 km^3 per year) of this water is consumed, mainly by agriculture through evaporation in irrigated cropland. The remaining 56% (2,212 km^3 per year) is released into the environment as wastewater in the form of municipal and industrial effluent and agricultural drainage water (see Figure 1).

A country's level of industrial and municipal wastewater treatment is generally a reflection of its income level. On average, high-income countries treat about 70% of the wastewater they generate, while that ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% of industrial and municipal wastewater undergoes treatment of any kind (Sato et al., 2013). This exasperates the situation for the poor, particularly in slums, who are often directly exposed to wastewater due to a lack of water and sanitation services.

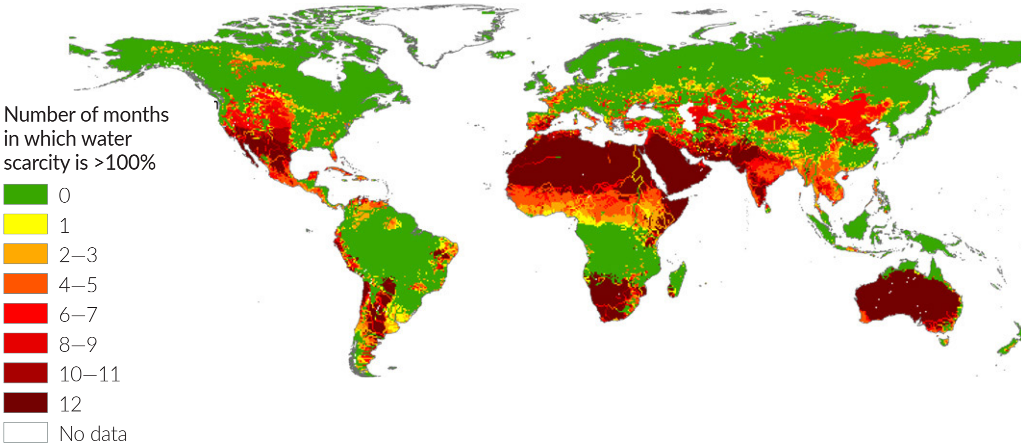
Figure 1 **Fate of freshwater withdrawals: Global consumption and wastewater production by major water use sector (circa 2010)**



Source: Based on data from AQUASTAT (n.d.a.); Mateo-Sagasta et al. (2015); and Shiklomanov (1999).

Contributed by Sara Marjani Zadeh (FAO).

Figure 2 Number of months per year in which the volume of surface water and groundwater that is withdrawn and not returned exceeds 1.0 at 30 x 30 arc min resolution (1996–2005)*



*Quarterly averaged monthly blue water scarcity at 30 × 30 arc min resolution. Water scarcity at the grid cell level is defined as the ratio of the blue water footprint within the grid cell to the sum of the blue water generated within the cell and the blue water inflow from upstream cells. Period: 1996–2005.

Source: Mekonnen and Hoekstra (2016, Fig. 3, p. 3).

These estimates support the often-cited approximation that, globally, it is likely that over 80% of wastewater is released to the environment without adequate treatment (WWAP, 2012; UN-Water 2015a).

There also appears to be significant variability across different regions. In Europe, 71% of the municipal and industrial wastewater generated undergoes treatment, while only 20% is treated in the Latin American countries. In the Middle East and North Africa (MENA), an estimated 51% of municipal and industrial wastewater is treated. In African countries, the lack of financial resources for the development of wastewater facilities is a major constraint in managing wastewater, while 32 out of 48 Sub-Saharan African countries had no data available on wastewater generation and treatment (Sato et al., 2013).

The treatment of wastewater and its use and/or disposal in the humid regions of high-income countries (e.g. North America, northern Europe and Japan) are motivated by stringent effluent discharge regulations and public awareness about environmental quality. The situation is different in high-income countries in drier regions (e.g. parts of North America, Australia, the Middle East and southern Europe), where treated wastewater is often used for irrigation, given the increasing competition for water between agriculture and other sectors.

The persistent expansion of sewerage and the consequent increases in wastewater volume generate pressure on existing treatment facilities, and in some cases can lead to suboptimal performance.

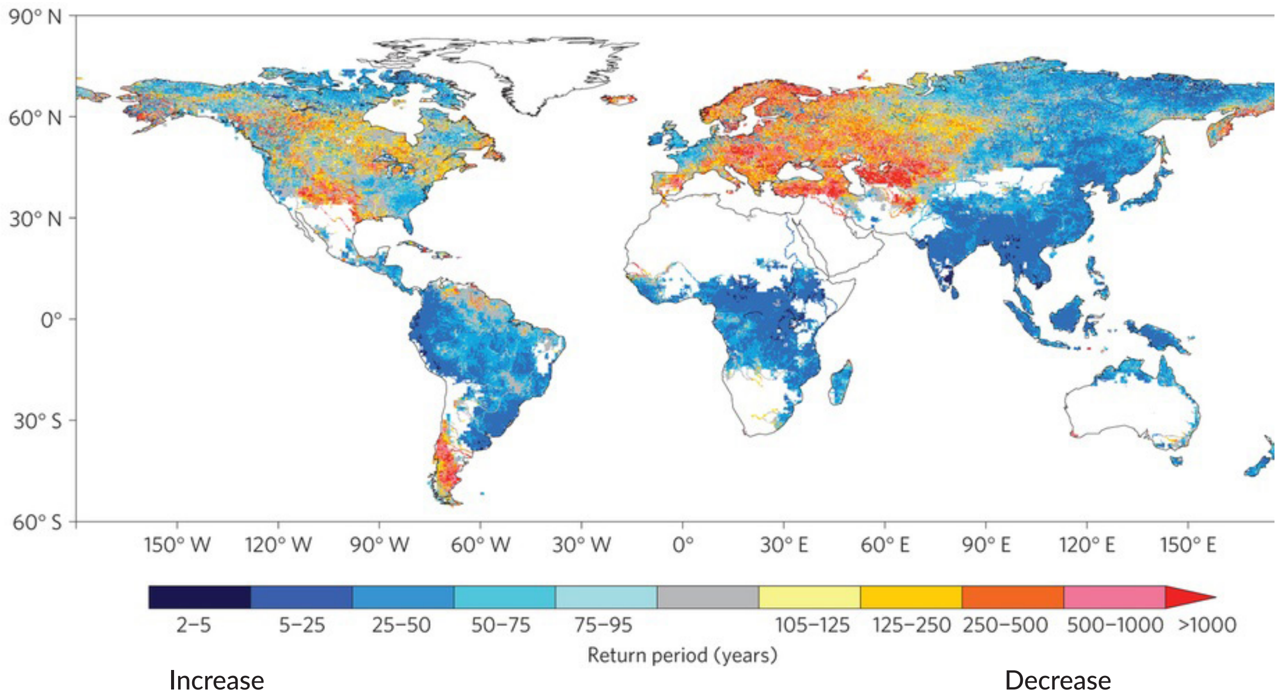
Even when wastewater is collected and treated, the final quality of the wastewater discharged may be affected by poor operation and maintenance, as well as overflow during storm events, when wastewater is allowed to bypass the treatment plant. Thus, much of the wastewater is not treated (or inadequately treated) and discharged in water bodies, and subsequently affects the water quality (and its availability) for users downstream.

Global water availability – Scarcity growing more severe by the year

Water resources (surface water and groundwater) are renewed through the continuous cycle of evaporation, precipitation and runoff. The water cycle is driven by global and climatic forces that introduce variability in precipitation and evaporation, which in turn define runoff patterns and water availability over space and time (modulated by natural and artificial storage). Observations over the past decades and projections from climate change scenarios point towards an exacerbation of the spatial and temporal variations of water cycle dynamics (cf. IPCC, 2013). As a result, discrepancies in water supply and demand are becoming increasingly aggravated.

Recent research has demonstrated that two-thirds of the world's population currently live in areas that experience water scarcity for at least one month a year (see Figure 2). Noteworthy is that about 50% of the people facing this level of water scarcity live in

Figure 3 Projected changes in flood frequency*



* Illustrated as the change of the return period of a 100-year flood. The simulations show the median of the outputs of 11 Global Circulation Models (GCMs) under the future scenario RCP 8.5 and the difference between periods 2071–2100 and 1971–2000 are compared.

Source: Hirabayashi et al. (2013, Fig. 1a).

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China and India. Such a month-by-month assessment of water scarcity is essential, as the water stress that results from dry periods can be masked by annual averages of water availability. Grid-based assessments, as shown in Figure 2, can be easily aggregated to the country scale, and provide more insights into the variability within the country. Average numbers can be misleading, particularly in countries with distinct spatial variations of water resources and uses as, for instance, Australia, Brazil, Chile, Russia and the USA.

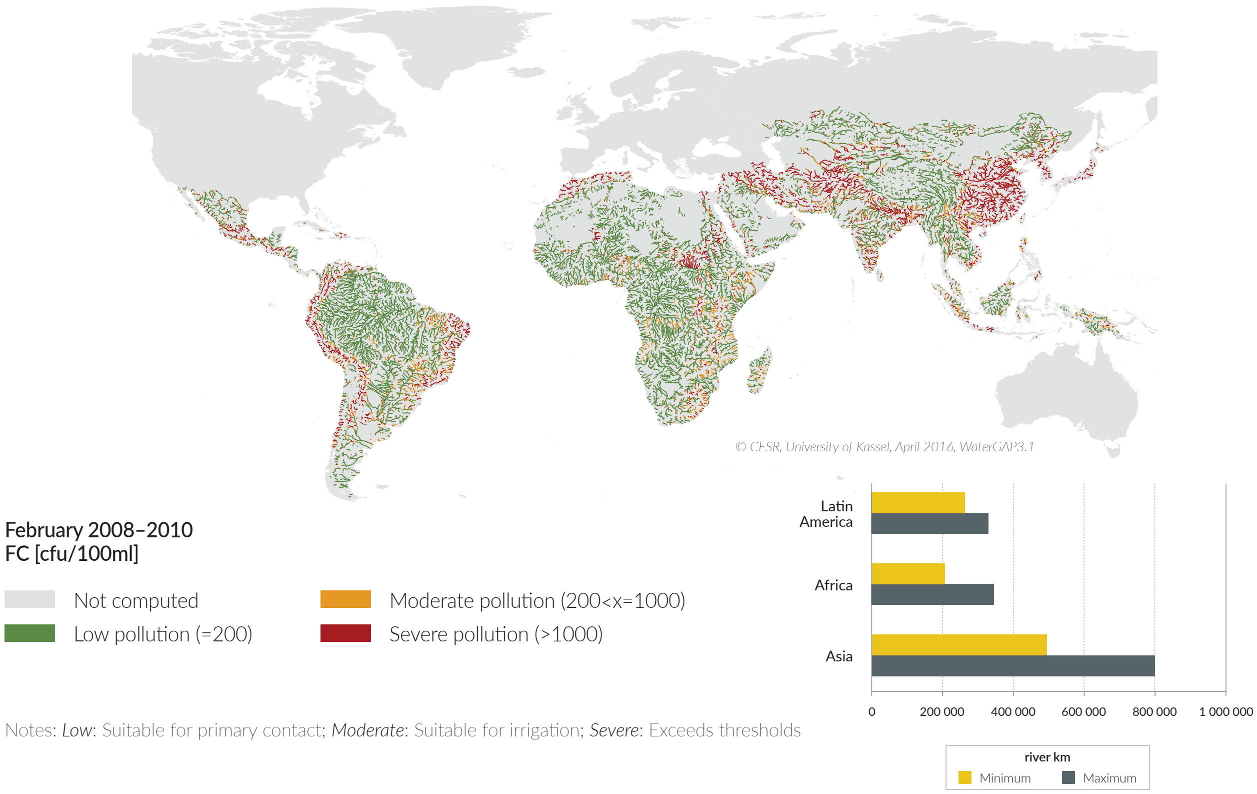
About 500 million people live in areas where water consumption exceeds the locally renewable water resources by a factor of two (Mekonnen and Hoekstra, 2016). This includes parts of India, China, the Mediterranean region and the Middle East, Central Asia, arid parts of Sub-Saharan Africa, Australia, Central and Western South America, and Central and Western North America. Areas, where non-renewable resources (i.e. fossil groundwater; never a sustainable source) continue to decrease, have become highly vulnerable and dependent on water transfers from areas with abundant water.

Even though floods and droughts are a natural phenomenon and part of the spatio-temporal variable water cycle dynamics, the frequency and severity of floods and droughts have changed in many river basins worldwide, often due to a combination of climate change and human activities. Land use changes, including urbanization, river channelization and other human activities, modify the storage capacity of catchments and impact high flows as well as groundwater recharge and low flows. Changed storage capacity and runoff generation processes can increase the occurrence of water-related disasters. The frequencies of floods (Hirabayashi et al., 2013) and droughts (IPCC, 2013) are likely to change with increasing temperatures. The results of an ensemble of projections (see Figure 3) show a large increase in flood frequency (represented by the blue areas, where events that are now considered 100-year floods would increase in frequency) in many areas, including India, Southeast Asia and Central and Eastern Africa, while in other areas the projected flood frequency decreases (represented by the yellow/red areas).

Having too much (floods) or too little (drought) water, which is often accompanied by too dirty water (higher pollution concentrations in both extremes), make the necessity for wastewater use even greater.

The economic costs arising from river flooding worldwide could increase twentyfold by the end of the

Figure 4 Estimated in-stream concentrations of faecal coliform bacteria (FC) for Africa, Asia and Latin America (February 2008–2010)*



Notes: *Low*: Suitable for primary contact; *Moderate*: Suitable for irrigation; *Severe*: Exceeds thresholds

* Bar charts show minimum and maximum monthly estimates of river stretches in the severe pollution class per continent in the period from 2008 to 2010.

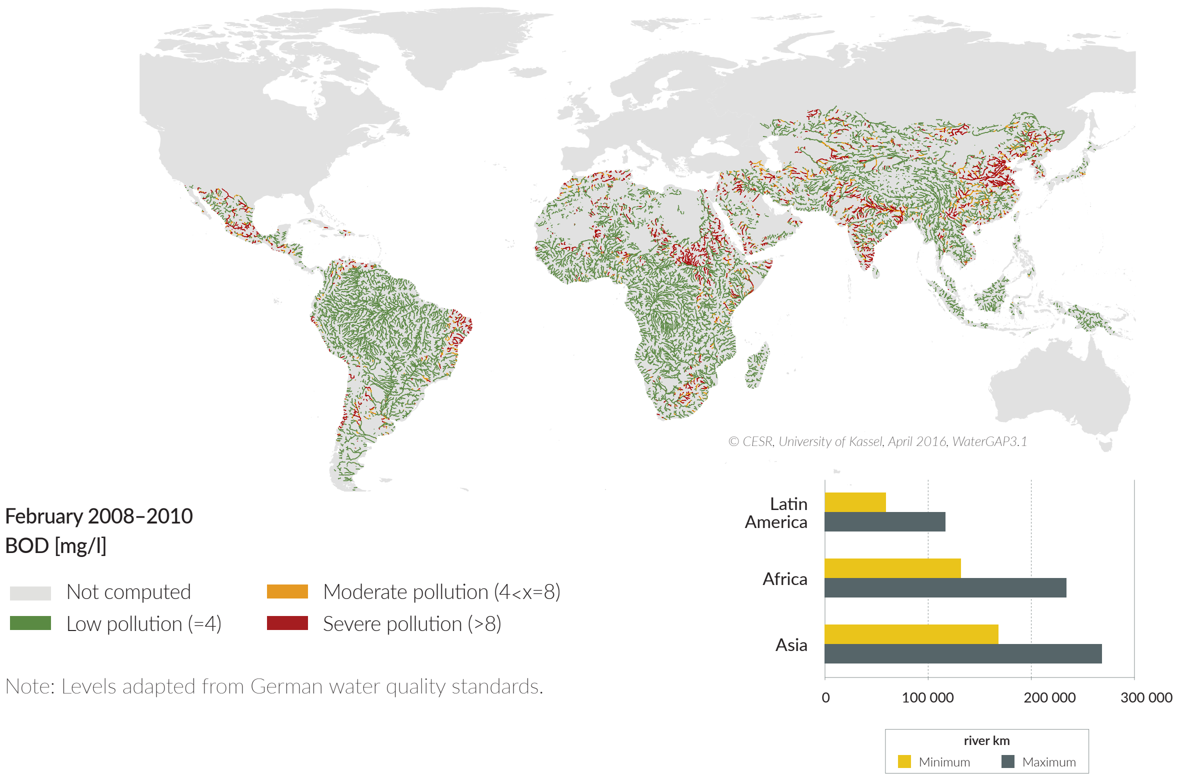
Source: UNEP (2016, Fig. 3.3, p. 20).

twenty-first century, if no further actions on flood risk reduction are taken. Over 70% of this increase can be attributed to economic growth in flood-prone areas, in addition to climate change (Winsemius et al., 2016). The Organisation for Economic Co-operation and Development (OECD, 2015a) cites climate scenarios based on modelling undertaken by Winsemius and Ward (2015), which shows that the flood damage in urban areas could reach US$0.7-1.8 trillion per year by 2080.

Globally, drought is arguably the greatest single threat from climate change but locally, sea-level rise (affecting coastal areas) or other threats could be larger (e.g. areas that are extremely vulnerable to floods or landslides). Consequences of drought can be very significant from a socio-economic and environmental perspective. Its impacts range from lower agricultural productivity and disruptions of ecosystem functioning to increased food prices, while insecurity and famine can trigger mass migration. The crisis in Syria was triggered, among other factors, by a historic drought in 2007–2010, which saw very little winter rainfall (partially due to climate change), and which made farming impossible on about 60% of the agricultural land, in spite of the knowledge and technology that were available. The livelihoods of thousands of farmers were impacted, which led to a rural-to-urban migration accompanied by an increased dependence on food imports, and to higher food prices, informal settlements, unemployment and social unrest. Consequently, brought about by civil war and other reasons, a large-scale migration movement started (Kelley et al., 2015). Some of the measures to increase the resilience to drought events include the acceptance of wastewater as a reliable source of water for agriculture and many other uses.

Global water demand is predicted to increase significantly over the coming decades. In addition to demand from the agricultural sector, which is currently responsible for 70% of water abstractions worldwide, large increases are predicted for industry and energy production (WWAP, 2015). Changing consumption patterns, including shifting diets towards highly water-intensive foods such as meat (i.e. 15,000 litres of water are needed for 1 kg of beef) will worsen the situation. It is therefore unsurprising that the World Economic Forum (WEF)

Figure 5 Estimated in-stream concentrations of biochemical oxygen demand (BOD) for Africa, Asia and Latin America (February 2008–2010)*



Note: Levels adapted from German water quality standards.

* Bar charts show minimum and maximum monthly estimates of river stretches in the severe pollution class per continent in the period from 2008 to 2010.

Source: UNEP (2016, Fig. 3.13, p. 33).

has consecutively assessed the water crisis as one of the major global risks over the past five years. In 2016, the water crisis was determined as the global risk of highest concern for people and economies for the next ten years (WEF, 2016).

Ambient water quality[1]

The availability of water resources is intrinsically linked to water quality. The pollution of surface water and groundwater may prohibit its different uses in the absence of costly pre-treatment. The deterioration of water quality is expected to increase further in the next decades, particularly in resource-poor countries in dry areas, which will further endanger human health and the environment, while constraining sustainable economic development (Veolia/IFPRI, 2015). The release of untreated wastewater from expanding human settlements and increasing industrial production generates physical, chemical and biological pollution, impacting both human and environmental health.

The presence of faecal coliforms, which originate from human and animal excreta, is used as an indicator of the presence of all potential pathogens in surface waters. Early findings from the global water quality monitoring programme show that severe pathogen pollution affects around one-third of all river stretches in Africa, Asia and Latin America (see Figure 4), putting the health of millions of people at risk (UNEP, 2016). Even though sanitation coverage has increased and treatment levels have improved in some countries (UNICEF/WHO, 2015), such improvements need to happen simultaneously in order to avoid increased contaminant loadings. This could probably explain the increased loadings of faecal coliform bacteria (FC) observed in Africa, Asia and Latin America over the last two decades.

Organic pollution (measured in terms of biochemical oxygen demand – BOD) can have significant impacts on inland fisheries, food

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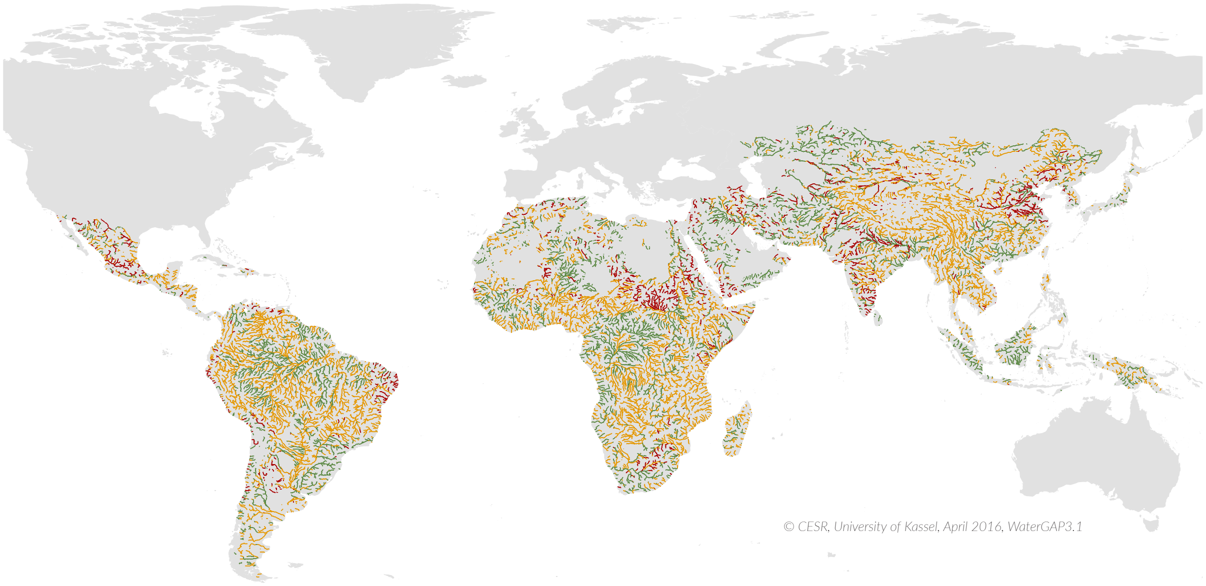
[1] This section is largely based on the Snapshot report (UNEP, 2016), which provides a comprehensive overview of the current water quality

Figure 6 Trend in BOD concentrations in rivers between 1990–1992 and 2008–2010*



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Trend of BOD in-stream concentration

⬜	Not computed	🟧	Increasing trend
🟩	Not increasing	🟥	Increasing trend of particular concern

* River stretches marked with orange or red have increasing concentrations between these two periods. River stretches marked with red have an "increasing trend of particular concern" meaning that in these stretches, the pollution level increased into the severe pollution category in 2008–2010, or that they were already in the severe pollution category in 1990–1992 and further increased in concentration by 2008–2010.

Source: UNEP (2016, Fig. 3.15, p. 34).

> **Globally, it is likely that over 80% of wastewater is released to the environment without adequate treatment**

security and livelihoods, severely affecting poor rural communities that rely on freshwater fisheries. Severe organic pollution already affects around one-seventh of all river stretches in Africa, Asia and Latin America (see Figure 5), and has been steadily increasing for years (see Figure 6) (UNEP, 2016).

The release of nutrients (nitrogen, phosphorus and potassium) and agrochemicals from intensive agriculture and animal waste can further accelerate the eutrophication of freshwater and coastal marine ecosystems and increase groundwater pollution. Most of the largest lakes in Latin America and Africa have seen increasing anthropogenic loads of phosphorus, which can accelerate eutrophication processes.

Increased discharges of inadequately treated wastewater, resulting from economic and industrial development, intensification and expansion of agriculture, and growing volumes of sewage from rapidly urbanizing areas are contributing to the further degradation of water quality in surface and groundwater around the world. As water pollution critically affects water availability, it needs to be properly managed in order to mitigate the impacts of increasing water scarcity.

PART I

BASELINE AND CONTEXT

CHAPTER 1

WWAP | Richard Connor, Angela Renata Cordeiro Ortigara, Engin Koncagül and Stefan Uhlenbrook

With contributions from: Birguy M. Lamizana-Diallo (UNEP); Sara Marjani Zadeh (FAO); and Manzoor Qadir (UNU-INWEH)

INTRODUCTION

Wastewater treatment plant

This introductory chapter frames the report by presenting the main issues and challenges related to the management of wastewater flows in the broader context of water resources management, underlying the importance of wastewater as a neglected but valuable resource, particularly under conditions of water scarcity.

Wastewater is a critical component of the water cycle and needs to be managed across the entire water management cycle: from freshwater abstraction, treatment, distribution, use, collection and post-treatment to its reuse and ultimate return to the environment, where it replenishes the source for subsequent water abstractions (see Figure 1.1). More often than not, however, attention to the management of water *after* it has been used has often been an overlooked component of the water management cycle. Wastewater management generally receives little social and political attention in comparison to water supply challenges, especially in the context of water scarcity. Yet, the two are intrinsically related – neglecting wastewater can have highly detrimental impacts on the sustainability of water supplies, human health, the economy and the environment.

Wastewater remains an undervalued resource, all too often seen as a burden to be disposed of or a nuisance to be ignored. This perception needs to change to correctly reflect its value – wastewater is a potentially affordable and sustainable source of water, energy, nutrients, organic matter and other useful by-products. Improved wastewater management, including the recovery and safe reuse of water and other key constituents, provides a great deal of opportunities. This is especially true in the context of a circular economy,[2] whereby economic development is balanced with the protection of resources and environmental sustainability, and where a cleaner and more sustainable economy has a positive effect on water quality.

Wastewater, which is also been referred to as 'used water' or 'effluent', can and has been defined in several different ways. As such, there is no single universally accepted definition for the term. For example, wastewater has been defined as "water that has been used and contains dissolved or suspended waste materials" (US EPA, n.d.a.), or "water that has been adversely affected in quality by anthropogenic activity" (Culp and Culp, 1971, p. 614). The term wastewater has also been equated with sewage, implying that the definition is limited to used water (from domestic, industrial or institutional sources) carried off by sewers, thus excluding the uncollected runoff from urban settlements and agricultural systems. However, as urban and agricultural runoff can be heavily polluted (and potentially become mixed with other wastewater streams), they are also important elements of the wastewater management cycle.

This report adopts a broad and inclusive definition of wastewater, adapted from Raschid-Sally and Jayakody (2008), which is used notably in the document 'Sick Water' produced by the United Nations Environment Programme (UNEP), the United Nations Human Settlement Programme (UN-Habitat) (Corcoran et al., 2010) and the UN-Water Analytical Brief on Wastewater Management (UN-Water, 2015a):

> Wastewater *is regarded as a combination of one or more of: domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (used water from washing and bathing); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban runoff; and agricultural, horticultural and aquaculture runoff* (Raschid-Sally and Jayakody, 2008, p. 1).

Several other related terms are equally difficult to define. For example, the terms 'reused', 'recycled' and 'reclaimed' have in some cases been used synonymously, whereas in other cases each has been specifically defined – albeit in different ways.

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[2] Definition provided in Lexicon (Annex 1).

The terms used in this report reflect the definitions adopted in the context of the 2030 Agenda for Sustainable Development (see Chapter 2) and several other international 'standards'. These are described in the Lexicon (see Annex 1). Unfortunately, these terms do not always distinguish between treated, partly treated or untreated wastewater, which is essential information in many contexts. Attempts have therefore been made throughout this report to explicitly specify the existing or required 'level' of treatment where appropriate. However, it is important to acknowledge the existing dilemma regarding multiple terminologies and to recognize that efforts will be required to develop a clear set of definitions in order to ensure consistency in monitoring and reporting related to wastewater. This is particularly critical for the selection of suitable indicators (see, for example, Box 1.1: The terms 'safe' and 'improved' in the MDG context (WWAP, 2015, p. 15)).

Historically, surface waters have been used as a means for the direct disposal of wastewater and other forms of waste, polluting water bodies downstream from cities, towns and villages (see Box 1.1). This practice

BOX 1.1 ARCHAEOLOGICAL WASTEWATER SYSTEMS: THE CASE OF ANCIENT ROME

Wastewater management has been practised for several millennia, evolving and improving throughout human history. The Etruscans, for example, developed channel systems to collect different water flows, and the Romans subsequently assimilated these techniques, improving and adapting them to their needs.

The first sewers of ancient Rome were built by Tarquinius Superbus around the seventh century BC. They consisted of an open-air channel system that drained water from the marshes at the bottom of the valleys of the seven hills (inhabitable land at the time) and conveyed it to the Tiber. These drainage systems slowly evolved and the Romans eventually built a complex system of sewers covered by stones, similar to modern drains. The exhaust of the latrines was sent into the main sewage system and then, through a central channel, into the closest river or stream.

The most advanced segment of the Roman sewage system was the covered Cloaca Maxima, the largest among the various wastewater collectors. First built as an open freshwater canal, it was transformed around the second and first centuries BC into a monumental underground tunnel with tuff walls and vaults.

Known as the "greatest sewer" (literal translation of its name) of Rome, the Cloaca Maxima is a masterpiece of hydraulic engineering and architecture. It is one of the most impressive sanitation artefacts of the ancient world, which provided the necessary drainage for the creation of the Roman Forum and became the central piece of a sanitation network that delivered hygiene services to the hills around Rome. An engraving by Piranesi shows the manifold, as it appeared in 1778, where wastewater was discharged into the Tiber River near Ponte Palatino.

However, the Tiber River eventually became highly polluted, creating a severe problem for the Romans who used its water for drinking, cooking, washing and other purposes. Discharging sewers downstream of the city were not sufficient to guarantee adequate water quality upstream. Furthermore, because the drainage system conveyed sewage and urban runoff (i.e. a 'combined sewer system'), reflux from the large openings along the streets would often occur during heavy precipitation events, thus exposing Romans to raw sewage.

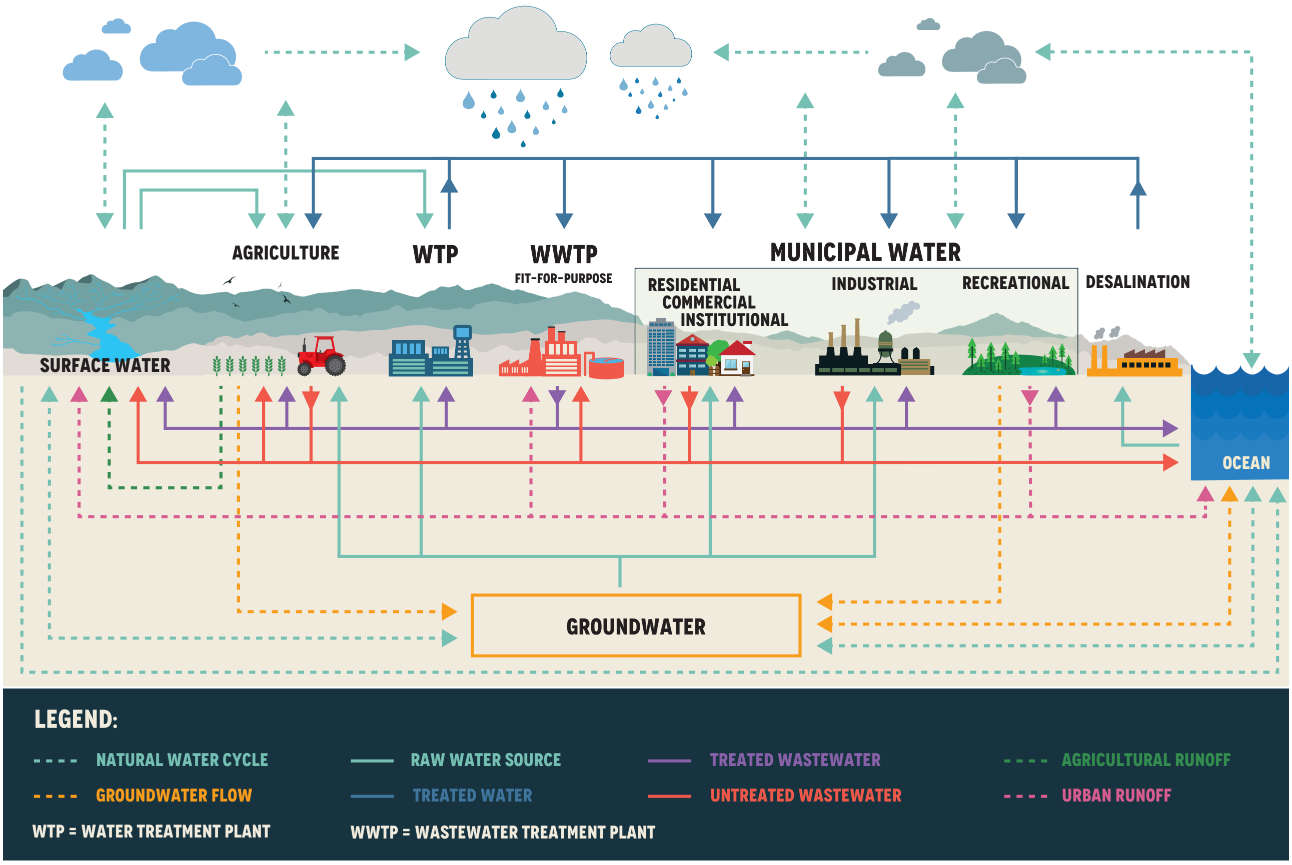
To drain the rainwater from the streets into the Cloaca, the Romans built special circular drains shaped as large masks, representing river gods swallowing water (the famous Mouth of Truth was probably one of these). Another distinctive feature of the Roman sewage system was the required fee for using the public latrines or renting chamberpots, making it one of the first historical examples of a user-pays approach to sanitation services.

An 1889 study of the Cloaca Maxima and some other sewers led to the restoration of parts that could be connected to the 'modern' sewer system and used in a project that continues to benefit Rome to this day.

Sources: Ammerman (1990); Bauer (1993); Narducci (1889); Lanciani (1890); and Bianchi (2014).

Contributed by Chiara Biscarini and Lucio Ubertini (UNESCO-IHP Italy).

Figure 1.1 Wastewater in the water cycle



Source: WWAP

has decreased in most developed countries since the late nineteenth and early twentieth centuries with the development of wastewater collection and treatment systems (UNEP, 2015a) and advances in solid waste management, which led to significantly public health benefits. However, the release of untreated wastewater into the environment remains common practice, especially in developing countries, with direct impacts on human health (with notably greater risks to women), the environment and economic productivity (see Table 1.1).

With so little wastewater undergoing treatment, and even less being used after treatment, there remains an enormous opportunity to reuse treated water in a sustainable way, and to extract some of the recoverable by-products that it contains. Under appropriately controlled conditions, the use of untreated wastewater also offers great potential for lessening the burden on surface and underground freshwater supplies, especially in arid and semi-arid regions, and other locations that experience chronic or recurring water scarcity.

1.1 Wastewater flows

Wastewater flows are as varied as its sources and the types of constituents they contain, with the latter being a function of the former. Figure 1.2 provides an overview of the main wastewater flows, from their generation at the source to their ultimate fate. Uncollected wastewater (and all its constituents) ultimately ends up in the aquatic environment. This is also the case for wastewater that is collected and disposed of without treatment, the proportion of which can in some cases be considerable (see Figures 4.4 and 4.5). Wastewater treatment can allow for the separation of water and other constituents, which can then be reused or disposed of.

1.1.1 The wastewater management cycle

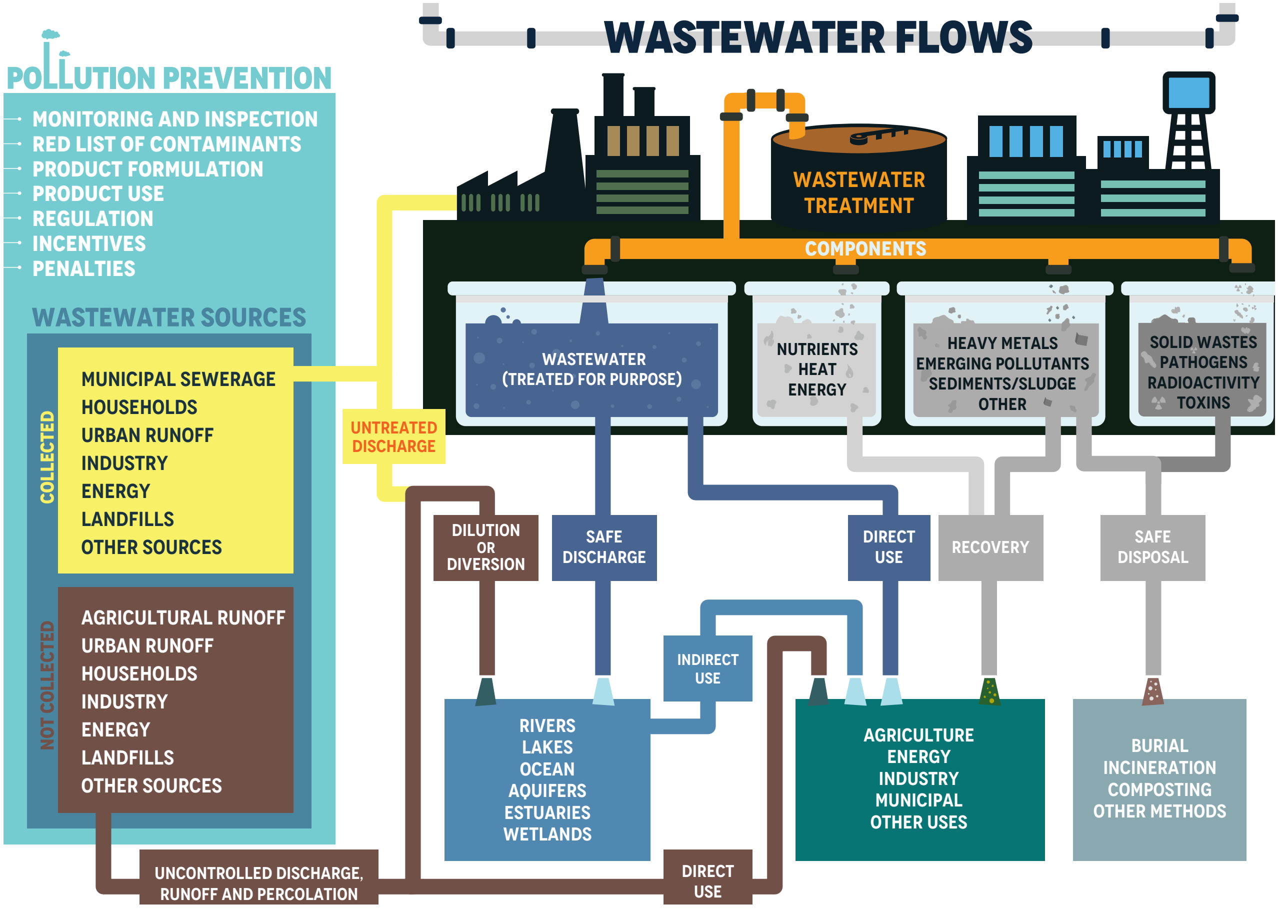
Controlling and regulating the various wastewater flows is the ultimate purpose of wastewater management. The wastewater management cycle can be broken down into four basic interconnected phases or steps:

Table 1.1 Examples of negative impacts of untreated wastewater on human health, the environment and productive activities

Impacts on	Examples of impacts
Health	• Increased burden of disease due to reduced drinking water quality • Increased burden of disease due to reduced bathing water quality • Increased burden of disease due to unsafe food (contaminated fish, vegetables and other produce irrigated) • Increased risk of disease when working or playing in wastewater-irrigated area
Environment	• Decreased biodiversity • Degraded aquatic ecosystems (e.g. eutrophication and dead zones) • Foul odours • Diminished recreational opportunities • Increased greenhouse gas emissions • Increased water temperature • Bioaccumulation of toxins
Economy	• Reduced industrial productivity • Reduced agricultural productivity • Reduced market value of harvested crops, if unsafe wastewater is being used for irrigation • Reduced opportunities for water-based recreational activities (reduced number of tourists, or reduced willingness to pay for recreational services) • Reduced fish and shellfish catches, or reduced market value of fish and shellfish • Increased financial burden on healthcare • Increased barriers to international trade (exports) • Higher costs of water treatment (for human supply and other uses) • Reduced prices of properties near contaminated water bodies

Source: Adapted from UNEP (2015b, Table 1, p. 15).

Figure 1.2 Wastewater flows



Source: WWAP.

a) **The prevention or reduction of pollution at the source, in terms of pollution load and volume of wastewater produced**. Prohibiting or controlling the use of certain contaminants to eliminate or limit their entering into wastewater streams through regulatory, technical and/or other means. This step also includes measures to reduce the volumes of generated wastewater (e.g. demand management and increased water use efficiency).

b) **The removal of contaminants from wastewater streams**. Operational systems (including collection infrastructure) and treatment processes that remove various constituents of wastewater (i.e. contaminants) so that it can be safely used or returned to the water cycle with minimal environmental impacts. There are several types and levels of wastewater treatment, the choice of which is dependent on the nature of the contaminants, the pollution load and the anticipated end use of the effluent.

c) **The use of wastewater (i.e. water reuse)**. Safe use of treated or untreated wastewater under controlled conditions for beneficial purposes. Historically used primarily for irrigation, wastewater treatment technologies have now advanced to allow for the use of treated wastewater for other uses, provided that the level of treatment and the quality of the effluent are 'fit-for-purpose'.

d) **The recovery of useful by-products**: Various constituents of wastewater can be extracted, either directly (e.g. heat, nutrients, organic matter and metals) or via supplementary transformation processes (e.g. biogas from sludge or biofuels from microalgae). There is a growing number of potentially cost-effective opportunities for extracting useful materials from wastewater, such as nitrogen and phosphorus, that can be transformed into fertilizer.

An additional role of the wastewater management cycle is to mitigate any negative impacts on human health, the economy and the environment.

When taking into account the multiple benefits of improved wastewater management, several of these processes can be considered cost-effective, thus adding value across the wastewater management cycle while supporting the further development of water supply and sanitation systems.

Based on the assumption that it is possible to align water quality requirements with water use locations, multiple use systems with cascading reuse of water from higher to lower water quality can make water reuse more affordable than providing extensive water treatment at each point of abstraction along a river basin (UNEP, 2015c).

1.2 Wastewater as a resource: Seizing the opportunities

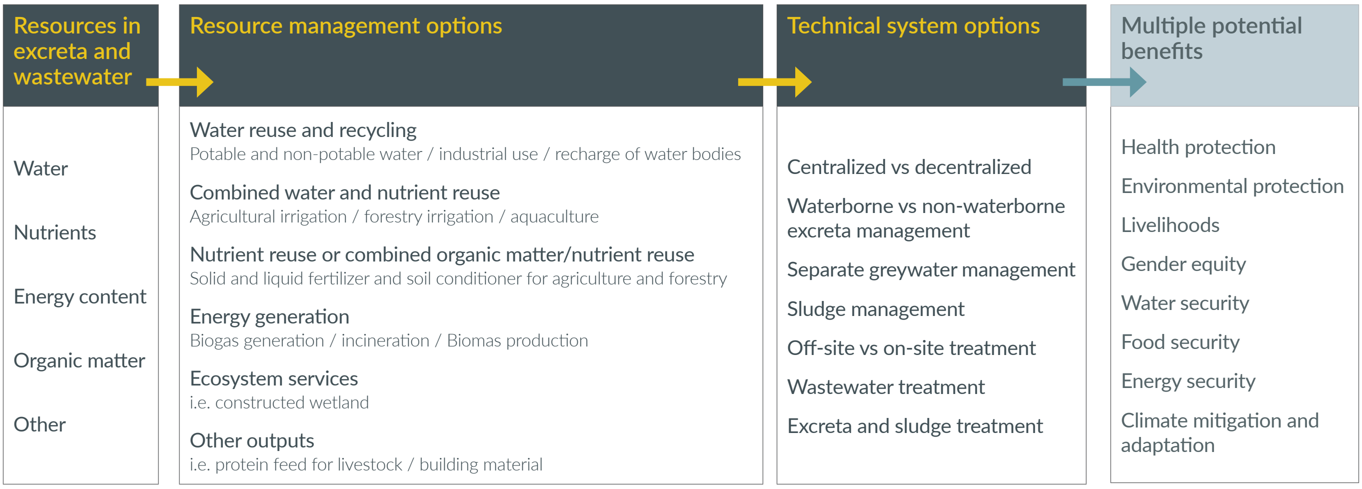
In practice, the goal is to go beyond mere pollution abatement and to seek to gain value from wastewater, if for no other reason, as an additional means of paying for wastewater management and for enhancing the economic sustainability of the system.

However, wastewater management is already an important part of several different resource cycles and is well-positioned to play a central role in the circular economy. Using appropriately treated water for agriculture and power generation enhances opportunities for food and energy security, and can help alleviate the stresses brought about by increasing demand for water. This will have positive repercussions on freshwater supplies, human and environmental health, income generation (livelihoods) and poverty alleviation. Furthermore, water reuse can generate new business opportunities and support the advancement of a green economy.

Aquatic ecosystems (e.g. ponds, wetlands and lakes) offer additional, low-cost solutions for enhancing wastewater management, provided they are managed sustainably. Although planned use and functional markets of wastewater for ecosystem services is a relatively recent phenomenon, the valuation of treated wastewater use for ecosystem services reveals favourable environmental and economic benefits.

The informal use of untreated wastewater is already occurring widely, out of simple convenience or as a matter of sheer need, and all too often in the absence of appropriate safety control measures. While measures that promote the direct use of certain types of untreated wastewater may be relatively easy to implement, the cost of developing treatment systems for recovering wastewater from certain specific human activities may be prohibitive in some cases. There can also be a mismatch between the location and timing of the source of wastewater, and its eventual use. Wastewater management systems, therefore, need to be designed based on its characteristics (e.g. origin, components and level of contaminants) and the intended end use of the effluent stream, including any useful by-products, as these will dictate the most appropriate and practical wastewater source.

Figure 1.3 Framing wastewater management from a resource perspective



Source: Andersson et al. (2016, Fig. 3.1, p. 27).

There are strong economic arguments in favour of optimizing freshwater-use efficiency, managing wastewater as a resource and eliminating (or at least reducing) pollution at the point of use. Utilizing wastewater at, or as close as possible to, its source generally increases cost-efficiency due to the lower costs of conveyance. The fact that so little wastewater management is currently occurring, particularly in developing countries, means that there are vast opportunities for water reuse and for the recovery of useful by-products, provided the appropriate incentives and business models are in place to help cover the substantial costs. Recent market studies also show that there is a positive trend in water and wastewater treatment investments in developing countries. Worldwide, the annual capital expenditures on water infrastructure and wastewater infrastructure by utilities have been estimated at US$100 billion and US$104 billion, respectively (Heymann et al., 2010).

Since wastewater management is implemented at the local level, responses and technical solutions will need to be location-specific (see Chapter 3). In this respect, there are opportunities in further integrating wastewater management, including sanitation and faecal sludge management (FSM), with water resources and solid waste management. This requires governance structures that foster collaboration across institutional boundaries, as well as accountability and compliance with regulations for wastewater use and the extraction/use of recovered by-products. Above all, wastewater management needs to be planned from ‘upstream’, at the source, in order to complement end-of-pipe solutions ‘downstream’.

A number of pressures on water resources are driving the need for the enhanced use of wastewater. Population growth, urbanization, changing consumption patterns, climate change, loss of biodiversity, economic growth and industrialization all have an impact on water resources and wastewater streams, with repercussions on atmospheric, land and water pollution. An improved approach to wastewater management will help alleviate the impact of some of these pressures.

From a resource perspective (see Figure 1.3), sustainable wastewater management requires: i) supportive policies that reduce the pollution load upfront; ii) tailored technologies that enable fit-for-purpose treatment to optimize resource utilization; and iii) taking account of the benefits of resource recovery. Such a perspective promotes the implementation of innovative financial mechanisms, while embracing a precautionary approach and the polluter-pays principle. It is the responsibility of national governments to provide the policy environment for equitable tariff structures that help ensure the operation and maintenance of existing infrastructure, and attract new investments along the wastewater management cycle.

CHAPTER 2

WWAP | Angela Renata Cordeiro Ortigara and Richard Connor

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WASTEWATER and the SUSTAINABLE DEVELOPMENT AGENDA

Rooftop garden in The University of Warsaw (Poland)

This chapter examines wastewater management in the context of the 2030 Agenda for Sustainable Development, with particular attention given to the efforts required in promoting synergies and addressing potential conflicts between the water goal and other SDGs.

2.1 2030 Agenda for Sustainable Development

On 25 September 2015, 193 Member States of the United Nations (UN) General Assembly adopted the 2030 Agenda for Sustainable Development with a set of goals to end poverty, protect the environment, and ensure prosperity for all. The Agenda includes 17 Sustainable Development Goals (SDGs) (see Figure 2.1), each with specific targets to be achieved over a 15-year period (UNGA, 2015a). The SDGs are interlinked and indivisible, and build on the progress and lessons learned from the Millennium Development Goals (MDGs, 2000-2015).

Figure 2.1 The Sustainable Development Goals

Source: UN (n.d.a.).

Within the MDG framework, MDG Target 7c called on Member States to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. Whereas the target related to drinking water was reported as achieved three years ahead of time (UNICEF/WHO, 2012), the sanitation target was not achieved. In fact, while 2.1 billion have gained access to improved sanitation facilities since 1990, 2.4 billion people still do not have access to improved sanitation and nearly 1 billion people worldwide still practice open defecation (UNICEF/WHO, 2015).

The experience of the MDGs showed that a broader, more detailed and context-specific goal was needed for water, going beyond the issues of supply and sanitation, which SDG 6 of the 2030 Agenda has addressed by calling for the improvement of water resource management in a broad, inclusive and integrated way. As such, it places a particular emphasis on: drinking water, sanitation and hygiene; water quality and wastewater; water use efficiency and scarcity; integrated water management; protection of ecosystems; international cooperation and capacity building; and stakeholder participation (see Table 2.1).

Goals and targets will be monitored and reviewed using a set of global indicators, but it is up to each country to define its national objectives concerning both wastewater treatment and water quality (UNGA, 2015a).

Measuring progress in the 2030 Agenda depends on how specific, measurable, attainable, relevant and time-bound (SMART) the indicators are for this task. The Inter-agency Expert Group on SDG Indicators (IAEG-SDGs) was established to develop an indicator framework for measuring progress towards monitoring the goals and targets of the 2030 Agenda at the global level, and to support its implementation. Member States will also likely develop their own national- and regional-level indicators to complement the proposed global level indicators to be approved by the UN General Assembly.

Two global-level indicators have been proposed to track progress for SDG Target 6.3, which is the most closely related to wastewater management (UN-Water, 2016a):

> **6.3.1 Proportion of wastewater safely treated:** Safely treated wastewater generated by households (sewage and faecal sludge) and economic activities (e.g. industries) in proportion to total wastewater generated by households and economic activities.
>
> **6.3.2 Proportion of water bodies with good ambient quality:** Proportion of water bodies (area) in a country with good ambient water quality compared to all water bodies in the country. 'Good' indicates an ambient water quality that does not damage ecosystem

Improved wastewater treatment and the increase in water reuse, as called for in SDG Target 6.3, will support the transition to a circular economy

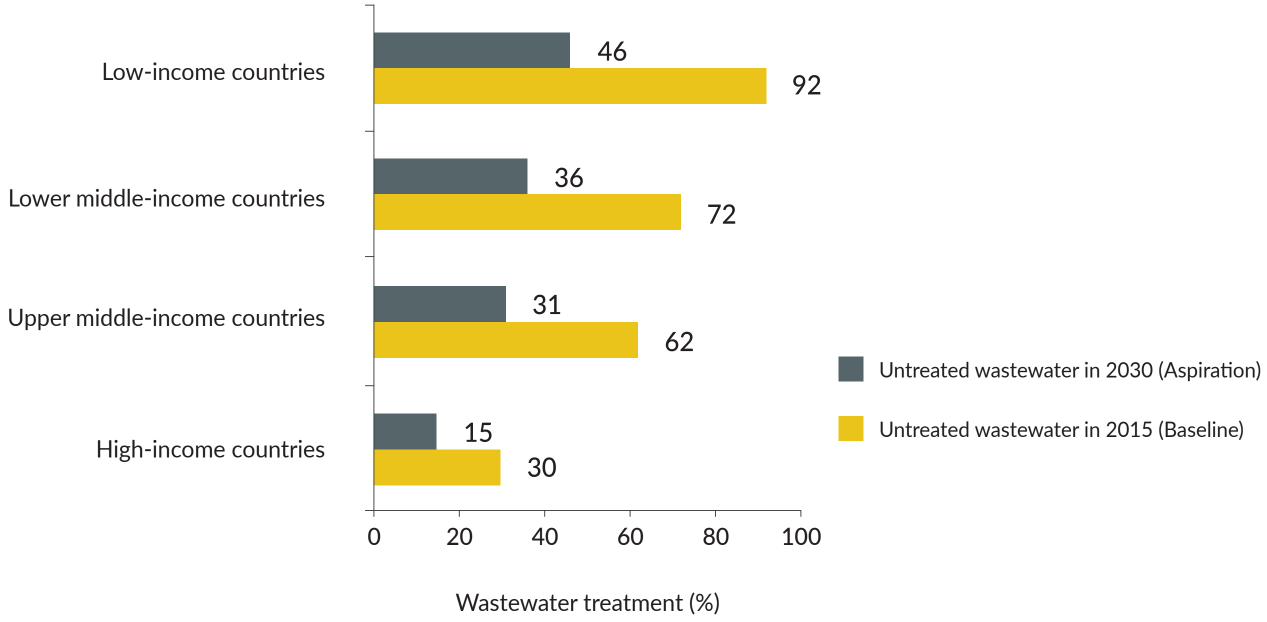
Table 2.1 SDG 6 targets and indicators

SDG 6 Ensure availability and sustainable management of water and sanitation for all	
TARGET	INDICATORS
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2.1 Proportion of population using safely managed sanitation services, including a handwashing facility with soap and water
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1 Proportion of wastewater safely treated 6.3.2 Proportion of bodies of water with good ambient water quality
6.4 By 2030, substantially increase water use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0–100) 6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time
6a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	6.a.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan
6b Support and strengthen the participation of local communities in improving water and sanitation management	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

*Source of indicators: UN-Water (2016a).

Source: UNGA (2015a).

Figure 2.2 Percentage of untreated wastewater in 2015 in countries with different income levels and aspirations for 2030 (50% reduction over 2015 baseline)



Source: Based on data from Sato et al. (2013).

functions and human health according to core ambient water quality indicators.

One of the challenges to monitoring SDG Target 6.3 indicators is the lack of data relating to virtually all aspects of water quality and wastewater management, particularly in developing countries. Reliable data generate social, economic and environmental benefits in both public and private sectors as they can underpin advocacy, stimulate political commitment and investments, and inform decision-making on all levels (UN-Water, 2016a).

In order to achieve SDG Target 6.3, significant investments will be required in new infrastructure (grey and green, in locally appropriate combinations) and appropriate technologies to increase the treatment and use of wastewater. Investments are also needed to upgrade the current infrastructure, operate and maintain existing and new infrastructure, develop capacity in water resources management, and monitor and control the quality of water and wastewater (UN-Water, 2015a). Due to the differences in the current levels of wastewater treatment overall, the efforts required to achieve SDG Target 6.3 will place a higher financial burden on low-income and lower middle-income countries (see Figure 2.2), putting them at an economic disadvantage compared to high-income and upper middle-income countries (Sato et al., 2013).

2.2 Potential synergies and conflicts

Achieving the 2030 Agenda for Sustainable Development will require concerted efforts to manage the potential conflicts and synergies between SDG 6 and other SDGs. A careful analysis of goals and targets may highlight conditions, where the achievement of one goal may favour the achievement of another. Conversely, situations where achieving one goal may hinder the achievement of another will require the identification of acceptable trade-offs (UN-Water, 2016b).

2.2.1 Potential synergies

SDG 6 cannot be fully achieved by addressing each target independently. For example, "increased access to sanitation (6.2) must be harmonised with increased wastewater treatment (6.3) in order to support good ambient water quality (6.3) and to guarantee healthy water-related ecosystems (6.6). Similarly, good ambient water quality (6.3) greatly facilitates the provision of safe drinking water (6.1), which must be provided sustainably (6.4), without negative consequences for water-related ecosystems (6.6). Increasing recycling and safe reuse (6.3) and water-use efficiency (6.4) make more water available for drinking (6.1) and other uses (6.4), and can reduce impacts on water-related ecosystems (6.6). Sustainable water supply and use (6.4), good ambient water quality (6.3), and healthy water-related ecosystems (6.6) are inter-dependent" (UN-Water, 2016b).

BOX 2.1 POVERTY, WASTEWATER MANAGEMENT AND SUSTAINABLE DEVELOPMENT– MULTIPLE CONNECTIONS

The 2030 Agenda for Sustainable Development (UNGA, 2015a) recognizes that eradicating poverty is the greatest of all global challenges. Poverty is multidimensional and includes deprivations, such as poor health and nutrition, lack of access to services, deficient schooling, and the psychological trauma of having to cope with rudeness and humiliation (Narayan et al., 2000; UNDP, 2010). Populations living in the poorest regions of the world are most affected by environment-related health issues (WHO, 2016a).

Diarrhoeal disease prevalence is linked to problems related to water, sanitation and hygiene (Prüss-Üstün et al., 2014). Access to improved sources of water and to sanitation is remarkably lower among poorer communities in low-income countries (UNICEF/WHO, 2015; UNICEF/WHO, 2014).

The health burden of poor sanitation and wastewater management is primarily borne by children: among children under 5 years old, 361,000 deaths could have been prevented in 2012 through reduction of risks related to inadequate hand hygiene, sanitation and water (Prüss-Üstün et al., 2014), while daily collection of water is mainly undertaken by girls and women (UNICEF/WHO, 2011). Household duties are more onerous under conditions of poverty, implying that the maintenance of family health falls disproportionately on women.

The most vulnerable and poorest members of society have the most to gain from improved sanitation and wastewater management. Investments in rural and urban sanitation as well as wastewater collection and treatment can therefore have high returns in terms of social and economic development. The average return on investments in sanitation is US$5.5 for each US$1 invested (Hutton and Haller, 2004). Certain solutions to the wastewater problem, such as recycling nutrients or extracting energy, can also bring in new opportunities for income generation and enlarge the resource base available to poor households (Winblad and Simpson-Hébert, 2004). An example is composting toilets, which have the potential of providing a low-cost solution to improved agricultural productivity alongside increased nutrition and the reduction of health and environmental impacts from open defecation (Kvarnström et al., 2014).

Contributed by Marianne Kjellén (UNDP) and Johanna Sjödin (UNDP Water Governance Facility at SIWI).

The achievement of SDG Target 6.3 is also a precondition to the achievement of other SDGs and the overarching goal of eradicating poverty (see Box 2.1). Appropriate wastewater collection and treatment helps protect the water quality in river basins and the goods and services that these provide, while significantly reducing the number of people exposed to water-related diseases (SDG Targets 3.3 and 3.9), providing related health and economic benefits and contributing to poverty alleviation (SDG Targets 1.1 and 1.2).

Water-related diseases and malnutrition prevent people from working and attending school, both of which strengthen the cycle of poverty (UNDP, 2006). Investing in water and wastewater management would provide particularly high returns by breaking the link between unsafe water and diseases that causes diarrhoea, particularly in developing countries. Prolonged diarrhoea intensifies poor health and malnutrition in children, and often leads to stunted growth due to poor nutrient absorption and loss of appetite (UNICEF/WHO, 2009). Therefore, improved sanitary conditions and wastewater management contribute to the success of nutrition enhancement strategies (SDG Target 2.2), reduces preventable deaths among children (SDG Target 3.2) and enhances children’s attendance and performance in school (SDG Target 4.7).

BOX 2.2 GENDER ROLES AND THE INTRODUCTION OF SAFE WASTEWATER USE

Where wastewater treatment is insufficient and wastewater irrigation common, safety measures can be implemented at critical control points along the food chain (from ‘farm to fork’) as described by the World Health Organization (WHO, 2006a) and illustrated by Amoah et al. (2011), among others. Care has to be taken about gender roles which can change from the farm level to wholesale, and to retail (Drechsel et al., 2013). Where risk awareness is low and not easy to develop, it is important to determine how best to motivate and trigger behaviour change, and encourage the adoption of gender-sensitive risk mitigation measures (Drechsel and Karg, 2013). In many cultures, women do not only carry the main responsibility for hygiene and health, but are also in charge of greywater or wastewater use, as seen for example in Jordan (Boufaroua et al., 2013), Tunisia (Mahjoub, 2013) and Vietnam (Knudsen et al., 2008). This connection offers significant potential for innovative training approaches to improve the social acceptance of safe wastewater use (Boufaroua et al., 2013).

Contributed by Carlos Carrión-Crespo and María Teresa Gutiérrez (ILO).

Reducing the burden of disease also reduces the time spent taking care of sick family members, leaving more time to participate in the formal economy (SDG 8) and in social and political decision-making. Women, who are often the main caregivers and who are responsible for the water supply within households, would also benefit from improved sanitation conditions and wastewater management, as they are frequently responsible for the management and use of greywater or wastewater in agriculture (see Box 2.2). Inclusive and gender-sensitive water management policies also support the achievement of gender equality (SDG 5).

Improved wastewater treatment and the increase in water reuse, as called for in SDG Target 6.3, will support the transition to a circular economy by helping reduce water withdrawals and the loss of resources in production systems and economic activities. The exchanges of energy, water and material flows in wastewater by-products can allow businesses to enhance their environmental performance and competitive capacity. These exchanges are often mutually beneficial, favouring a reduction in production costs, water consumption and/or wastewater treatment costs (SDG Targets 8.2 and 8.4).

Building climate-resilient wastewater infrastructure networks can decrease the direct economic losses caused by disasters (SDG Target 11.5), while increasing the capacity of human settlements to recover from natural hazards such as floods and droughts (SDG Target 13.1). Improved wastewater management also has great potential for reducing GHG emissions (SDG Target 13.2). Wastewater can be considered a reliable source of water in the planning and development of new settlements and water resource projects (SDG Target 11.6).

The achievement of SDG Target 6.3 also contributes to the reduction of land-based pollution in terrestrial and marine ecosystems (SDGs 14 and 15).

2.2.2 Potential conflicts

In cases where interlinkages between SDG Target 6.3 and the other SDGs are not mutually beneficial, it will be important to balance conflicting needs and manage trade-offs.

Ending hunger, increasing food sufficiency (SDG Target 2.1), and doubling smallholders' productivity and incomes (SDG Target 2.3) are essential to support poverty eradication (SDG 1). However, the achievement of SDG 2 also implies an increase in agricultural productivity, which may lead to an increase in water demand and the use of herbicides, pesticides and fertilizers, with a consequent decline in water quality and quantity if resources are not properly managed. The use of best agricultural practices needs to be promoted in parallel with the reduction of food waste (see Box 2.3).

BOX 2.3 WATER 'LOSS' FROM FOOD WASTAGE

Agriculture is the world's largest consumer of water. Several types of food, like vegetables, have very high water content (in some cases well above 90%). In Europe, for example, the manufacturing of food products consumes on average about 5 m^3 of water per person per day (Förster, 2014). At the same time, with as much as 1.3 billion tonnes of food wasted annually (WWF, 2015), 250 km^3 of water is being 'lost' per year due to food waste worldwide (FAO, 2013a). Food waste can be defined as the discarding of food that was fit for human consumption but has become spoiled, expired or otherwise unwanted (FAO, 2015). It can also include crops that are not harvested (because of low market prices, for example). At the global level, meat and cereals clearly stand out in the global proportion of food waste by 21.7% and 13.4%, respectively (Lipinski et al., 2013).

Contributed by University of Kassel.

Improving drinking water coverage in formal and informal settlements (SDG 11) is a matter of fundamental importance to the fulfilment of the human right to water and sanitation. This needs to go alongside the expansion of wastewater collection and treatment so as to avoid impacts on water quality, human health and the environment.

Increasing economic growth (SDG 8) and the development of small-scale industries (SDG Target 9.3) also present potential conflicts with the achievement of SDG Target 6.3 where pollution and the release of untreated wastewater are concerned. Economic development or improving 'the access of small-scale industries in developing countries to financial services' needs to occur in compliance with environmental health and safety regulations. The creation of an enabling environment where small-scale industries are required to respect environmental regulations in order to access to financial services can be a positive incentive.

Finally, reducing inequality within and between countries (SDG Target 10.1) means that ensuring adequate wastewater management services are available to all. This is one of the keys to achieving sustainable development and ensuring that enough water of good quality will be available for future generations.

CHAPTER 3

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GOVERNANCE

Regional meeting on sustainable development in Uganda

This chapter describes the governance frameworks through which wastewater is managed, including the many actors and their different roles, legal and regulatory instruments, financial challenges and opportunities for financing, and social and cultural aspects.

Wastewater management presents numerous challenges. In cases where wastewater is discharged untreated, those affected may be geographically or temporally far away from the polluter. For this and other reasons, society must act collectively to promote human health and protect water resources from pollution. The related governance challenges involve legal, institutional, financial, economic and cultural issues.

This chapter delves into the processes for policy-making, regulation and financing, and the related socio-cultural challenges of compliance and policy implementation.

3.1 Actors and roles

In order to realize the goals of water quality improvement and the protection of water resources, individuals and organizations must comply and act in the collective interest. The policy intentions, or wastewater management goals, are translated into laws and regulations, with responsibilities assigned to different actors. Policy outcomes depend largely on the way in which such responsibilities are implemented, at all levels, taking account of costs. Table 3.1 gives an overview of the governance functions relating to wastewater management. Ranging from policy-making and legislation to research and capacity development, it outlines typical primary and secondary roles and the necessary cross-collaborations in order to achieve coordinated policy implementation. Most roles relate to the more centralized solutions for managing wastewater, where alternative and local sanitation and drainage may involve many additional actors. Moreover, in relation to low-income or remote areas, there may be a lack of responsible or capable actors to lead policy development and implementation, requiring special support and attention from policy-makers. Everywhere, regulation must be well-designed and resources need to be made available for enforcement. Overcoming the practical difficulties of implementing water quality regulations can be particularly challenging for public sector organizations, even in highly developed countries.

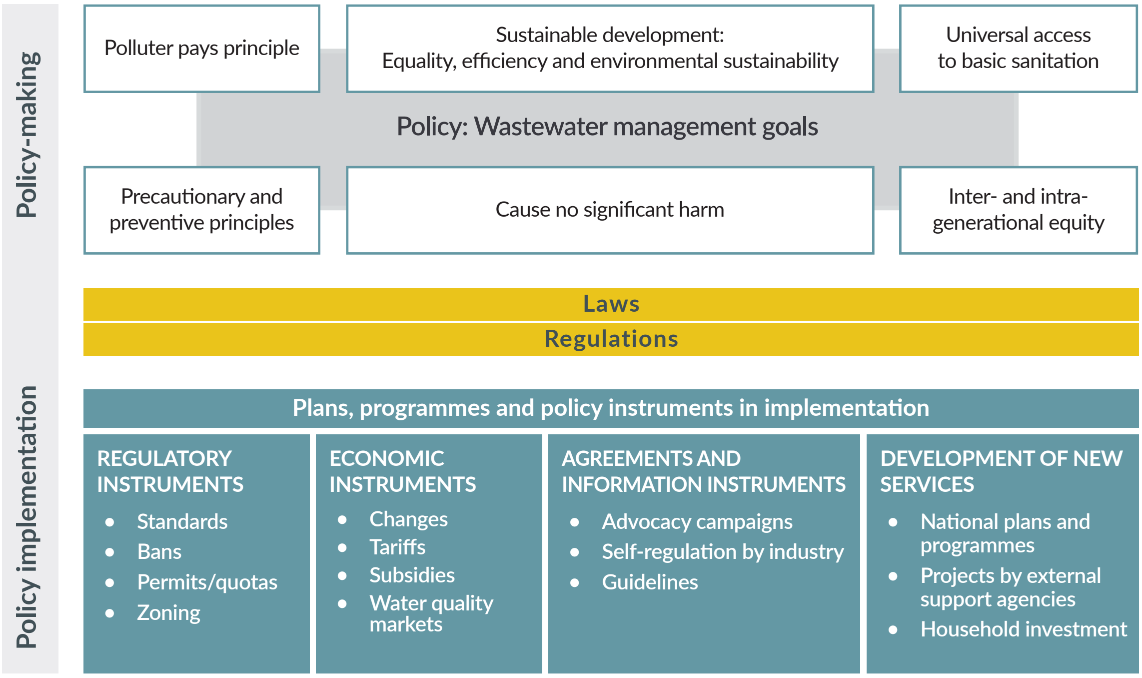
The coordination of actors across sectors is a challenge that goes well beyond wastewater management. There are several integrated and intersectoral approaches towards water and land management (upstream-downstream dynamics, urban water resources, etc.) that help to overcome 'silo' thinking, without which actors may pursue narrow or conflicting interests (cf. UNDESA, 2004; GWP, 2013). The coordination of systems with multiple technologies or patchy coverage is a particular challenge, which can be resolved either by ensuring that sewer connections are extended to all parts of a service area, or by integrating the actual solutions on the ground (e.g. FSM by vehicles or latrines managed by households into a coherently functioning system).

Public-private partnerships in the provision of wastewater services have spurred a wave of revisiting regulation, particularly during the 1990s. In order to contract private local or international firms to conduct services previously carried out by government departments or parastatals, new ways of licencing and overseeing operations were instituted in many countries (Finger and Allouche, 2002). It is increasingly recognized that improved regulatory oversight is required for both private and public service providers (Kjellén, 2006; Gerlach and Franceys, 2010).

Important differences exist in the scale of operations. Large-scale infrastructure, which is predominant in high-income countries, benefits from economies of scale, but requires strong centralized management and technical capacities. In low-income countries, large-scale centralized systems have a tendency to bypass informal or low-income settlements. Decentralization can be a strategy to overcome the patchy service coverage of centralized systems, but also occurs as a community response to incomplete service coverage (see Chapter 15).

About two thirds of the world's population have access to improved sanitation (UNICEF/WHO, 2015). Sewer connections to large centralized systems are most common in high-

Figure 3.1 Institutional levels of policy-making and implementation



Source: Developed by authors; design by Johanna Sjödin.

income countries, and in urban areas in China and middle-income countries of Latin America (Kjellén et al., 2012). The majority of people rely on some form of decentralized or self-provided services, sometimes with NGO support but commonly without any assistance from central authorities (see Figure 5.1). SDG 6 (see Chapter 2) sets a target of 'access to adequate and equitable sanitation and hygiene for all' by 2030 (UNGA, 2015a), recognizing that waterborne systems are unlikely to become universal.

The planning, construction, financing and operation of alternative systems should attentively involve the inhabitants themselves, which helps the development of local leadership, entrepreneurship and practical engineering. Property owners can take action, and may have responsibilities to reduce runoff volumes and impacts, but issues like drainage are not easy to manage at the local level. Municipal authorities or public works departments tend to have the primary responsibility for urban runoff. Yet, to avoid pollution, littering and the dumping of waste, the collaboration of all residents and businesses is crucial – and this requires a combination of advocacy, incentives and regulation. The Orangi Pilot Project in Karachi, Pakistan is a classic example where the community, aided by philanthropists, managed to construct an affordable condominium sewage system paid for by the local community (Hasan, 1988).

3.2 Policy, law and regulation

Global policy frameworks for wastewater include the 2030 Agenda (UNGA, 2015a), which builds further on other global policy instruments for water, environment and development as well as environmental principles, such as the prevention and precautionary principles and the polluter pays principle (UNCED, 1992). The global recognition of the human right to water and sanitation (UNGA, 2010; UNGA, 2015b) also has implications for wastewater policy, by calling upon Member States to adopt policies to increase access to sanitation and to ensure that water resources are protected from pollution (UNGA, 2014).

Regional bodies and national governments reflect these global agendas in their policies on water resource management, the provision of water services, and the management of wastewater and solid waste. Policy-makers set goals, embracing or relating to more general principles (see the circles in Figure 3.1), which may be enshrined into general law and detailed regulations (see layers in Figure 3.1).

3.2.1 Legal frameworks

Like the policies discussed above, the applicable laws also operate at different levels.

International obligations can become relevant when wastewater (e.g. effluents or agricultural runoff) flows into international rivers and lakes or aquifers. There are two main global treaties addressing the management of transboundary freshwater:

1. The *UN Convention on the Law of the Non-Navigational Uses of International Watercourses* (UN, 1997, entered into force in 2014) requires that States take all appropriate measures to

Table 3.1 Actors, roles and functions to govern wastewater

Actors Functions	Legislator/politician/ policy-maker	Regulators (environment, health, economic)	System owner (city, ministry, basin agency)
Law-making	Define and adopt laws through inclusive consultative process	Share expectations as to governance role	Share expectations as to governance role
Policy-making	Define and adopt policies to implement the law through inclusive consultative processes	Share information on current situation and policy preferences	Share information on current situation and policy preferences
Planning, coordination and budgeting	Define modalities for planning, coordination and budgeting	Share preferences through constructive participation	Lead consultations, define standards for service delivery; allocate and disburse budget
Financing wastewater management	Decide on subsidies and modalities for financing	Regulate tariffs and service quality	Strategic financial planning, decision on tariffs
Wastewater infrastructure development and operation of wastewater services and facilities	Guide standards/regulations for construction and operation of infrastructure	Regulate tariffs and service quality	Coordinate spatial planning, siting/zoning decisions; prepare call for tenders, depending on the type of services/goods
Regulation – monitoring and enforcement	Define regulatory framework	Implementation of regulatory framework (including collection of information from service providers and permit holders, ensuring compliance, inspections, etc.)	Report suspect actions
Redress mechanisms (including judiciary)	Define competent authorities for redress	Accountable or party to complaint	Accountable or party to complaint
Compliance and pollution prevention	Develop incentives for prevention and disincentives for pollution	Implement incentives (including monitoring and advocacy for pollution prevention and water-use efficiency)	Support implementation
Advocacy and communications	Define policy goals and defend space for communication	Advocacy for pollution prevention and water-use efficiency	Awareness-raising and information to the public; solicit compliant behaviours from industry and households
Capacity development	Defining policy goals for sector; and develop capacities	Monitor capacities and incentivize development	Support development
Research and innovation	Highlight research needs, ensure support to research and development (R&D)	Highlight research needs; incentivize R&D	Highlight research needs; guide and engage in R&D

*Shading relates to typical level of responsibility: darkest = leading, lightest = least involved

Source: Developed by authors and contributors.

	Operator/service provider	Academia/policy institutes/ think tanks	Producer/consumer (agriculture, industry, households)	Civil society, NGOs
	Share expectations as to governance role	Provide input for law design	Share expectations as to governance role through participation	Share civil society opinions as to governance processes to provide input into law design
	Share information on current situation and policy preferences	Share evidence-based input for policy design	Share information on current situation and policy preferences	Share information on current situation and policy preferences
	Share preferences through constructive participation	Share preferences through constructive participation	Share preferences through constructive participation	Share preferences through constructive participation
	Collect information on investment needs and supply costs	May provide information and advice	Pay tariffs and provide information on willingness and ability to pay	Monitor financial accountability; raise awareness regarding the cost of services.
	Construction; maintenance; operation; billing; revenue collection, customer relations	Can monitor processes and act as social witness in integrity pacts (corruption prevention tool)	Should be involved in issues like siting/zoning decisions, acceptability, etc.	Can monitor processes and act as social witness in integrity pacts (corruption prevention tool)
	Provide information on request	Conduct long-term studies and analyse processes	Industry to provide information on request	Report suspect actions to law enforcement authorities
	Accountable or party to complaint	Expert (*amicus curiae*)	Accountable or party to complaint	Party to complaint and/or expert (*amicus curiae*)
	Comply with regulation; improve technology and organization	Support implementation	Implement cleaner production and reuse technology; correct waste disposal; improve agricultural practices	Advocacy for pollution prevention and water use efficiency
	Advocacy for pollution prevention and water use efficiency	Long-term studies and analysis of processes; awareness-raising	Dialogue with partners and general audience about policy messages	Raise awareness
	Skills development and professionalization of wastewater management and services delivery	Provide training and education		
	Participate in research, development and test new technology solutions	Research on contaminants, pollution loads, ecological functions, system interactions, human behaviour	Participate in research, development and testing of new technology solutions	Highlight research needs, participate in research

*Shading relates to typical level of responsibility: darkest = leading, lightest = least involved prevent causing 'significant harm' to other States sharing an international watercourse (Art. 7) and that States cooperate to protect international watercourses (Art. 8). Many regional conventions also use these principles as they reflect customary international law.

2. The *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* (the Water Convention) was developed as a regional instrument by the UN Economic Commission for Europe (UNECE, 1992). It has come into force in 1996 and has been open to UN member states from across the globe since 2013. The Water Convention addresses transboundary impacts, the sustainability, precautionary and polluter pays principles (Art. 2), and includes obligations to control emissions of pollutants and for the prior licensing of wastewater discharges.

These Conventions have framed the development of regional and bilateral treaties and agreements. International environmental law is applicable to the management of solid waste, including hazardous waste, and the management of air pollution, all of which may affect water quality, sometimes far from the point of discharge.

At the regional level, the European Union (EU) Water Framework Directive (2000/60/EC) (EU, 2000) applies to the management of water quality, including wastewater. The Framework Directive on Waste uses the '3R's' approach – reduce, recycle, reuse – as well as the precautionary and polluter pays principles (2008/98/EC) (EU, 2008). Solid waste legislation is highly relevant to non-waterborne sanitation and to the management of sludge. The Protocol on Water and Health to the Water Convention (UNECE/WHO, 1999, entry into force in 2005) requires Parties to set national and local targets covering the entire water cycle, including sanitation, with the aim of protecting human health and well-being through improved water management, protection of water ecosystems, and preventing, controlling and reducing water-related diseases. Other regional water treaties, such as the Protocol on Shared Watercourses in the Southern African Region, first signed by the Southern African Development Community (SADC) in 1995 and revised in 2000 (SADC, 2000), and the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin (MRC, 1995), reflect the general provisions of the UN Watercourses Convention (UN, 1997) and customary international law, such as the no-harm rule and notification of planned measures, but do not have the level of detail with regard to cross-border wastewater management.

Most pollution control laws are developed and enforced at national or local levels. However, in a transboundary river basin, wastewater discharged in one country may have downstream effects in another country. International and regional frameworks can assist states in managing these cross-border effects. Box 3.1 shows an example of action taken at the regional, national and local levels to manage water and wastewater.

BOX 3.1 INTERNATIONAL INSTITUTIONAL FRAMEWORK FOR JOINTLY PROTECTING WATER QUALITY IN THE DANUBE AND THE BLACK SEA

The Danube River Basin is Europe's second longest river, draining water from 19 states into the Black Sea. Historically, the International Commission for the Protection of the Danube River* dealt with navigational uses. The cooperation in the Danube / Black Sea area is an example of partnerships working at different scales to meet multiple objectives, involving different actors and within the frameworks of transboundary, regional and national laws.

The Commission, being the overarching management group, has produced a Participation Strategy to involve stakeholders. Significant funding has been provided through the International Waters projects of the Global Environment Facility (GEF). This has included working with States and with the Commission to identify and implement an investment portfolio of nearly 500 projects, representing pollution reduction investments totalling over US$5 billion (Hudson, 2012).

Lack of wastewater treatment was an important driver in this investment programme. In 2010, the Budapest Central Wastewater Treatment Plant began operation as part of the 'Living Danube' project. It ensures that 95% of the wastewater from Budapest is treated before its return to the environment, whilst also recovering nutrients and energy.

*For further information, see www.icpdr.org/main/danube-basin

3.2.2 Regulation

In relation to environmental protection, regulation usually relates to the use of permits and licenses, the application of emission or wastewater quality standards, or zoning for land use (Sterner, 2003). Regulation also underpins the establishment of collection systems and treatment facilities by setting appropriate standards for treatment and reuse for different purposes. 'Economic' regulation is used in urban services, which includes the provision of drinking water and municipal wastewater management. This ensures that technical and service standards are met, and that tariffs and investment levels are sufficient to cover the costs of the service, while providing a reasonable rate of return for future investments (Groom et al., 2006). Solutions also need to be context-specific and reflect the different stages of development. Controlling or banning the use of certain substances is another means of preventing them from entering wastewater flows (see Box 4.2 and Section 5.4.1).

Regulations may address the treatment level or the process itself, by specifying 'secondary treatment', or the use of 'best available techniques' that may then be further defined. These may also regulate the quality of the effluent by setting emission standards. If there are downstream ambient standards for the receiving waters, these can be made to address trends and cumulative effects.

Where a State has little or no regulation regarding wastewater and its resources are limited, the WHO recommends measuring a small number of key parameters that have the highest relevance to water quality, rather than a wider set of standards that cannot be enforced (Helmer and Hespanhol, 1997). Guidelines can be issued that include a wider range of parameters, in order to help manage impacts downstream.

Large centralized systems benefit from economies of scale, but they take time to develop and are difficult to adapt to different socio-economic circumstances (see Chapter 12). In low-income countries, it is common to find that the practices described in policy intentions and regulatory instructions differ considerably from what is actually taking place on the ground (Ekane et al., 2012 and 2014).

Informal urban settlements across the globe also face particular challenges. Wastewater-related services (e.g. pit emptier and desludging companies) may be provided by informal private providers without appropriate control or support from relevant authorities. If the collection and transport, or recycling, of faecal sludge is not managed properly, this can have significant repercussions on human health.

Industrial wastewater may be treated on-site and recycled immediately, or discharged into the municipal wastewater stream (see Chapter 6).

The feasibility of water reuse depends on its origin and the intended reuse. In Australia, several states have targets for wastewater use and the Commonwealth government provides extensive guidance on the reuse of water (NRMMC/EPHC/NHMRC, 2009). Some States have developed regulatory frameworks, including for direct potable use (ATSE, 2013).

Safety precautions are particularly important in the case of wastewater reclamation for drinking water purposes. It requires the use of multiple barriers, using several techniques in series in order to secure water quality, as well as advanced control systems and, above all, excellent water quality records. As a result, these systems often present higher water quality standards than other (raw) water sources. Notwithstanding, extensive information campaigns and participation by the public are required to build trust in the system (see Chapter 16).

Untreated wastewater is regularly used for agricultural irrigation and for aquaculture (see Chapters 7 and 16). While blackwater use may provide valuable nutrients, it can also present hazards, not only for workers but also for the consumers of food products (WHO, 2006a).

3.3 Financing

Wastewater management is costly and suffers from collective action problems; the benefits accrue to the public and future generations, rather than directly to those who invest in improved treatment or reduced pollution. Further, the real benefits are only realized once everyone (or a sufficient number of actors) abides by the rules to protect water resources from pollution. In this way, sanitation and wastewater management is significantly more complicated and costly than drinking water supply (Jackson, 1996; Hophmayer-Tokich, 2006).

Economic instruments can be used to incentivize pollution prevention, but to be effective, they must be combined with information, advocacy and effective regulation. Liability rules for the release of pollutants or taxes on effluent can be established in accordance with the polluter pays principle (Olmstead, 2010).

Financing centralized wastewater infrastructure is dominated by capital costs. In most countries, new infrastructure has been financed through transfers of public money (OECD, 2010). Several low-income countries rely primarily on aid transfers to finance their water and sanitation sectors (WHO, 2014a). Middle-income countries also rely on aid transfers. In Panama, where strong political objection exists against tariff increases, tariffs have remained the same for more than two decades (WHO, 2014a; Fernández et al., 2009).

The reluctance to assign direct resources to sanitation and wastewater is shown by the TrackFin[3] initiative that was piloted in Brazil, Ghana and Morocco. As reported in the UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) survey, most funds were found to be directed to drinking water supply in the urban sector, even though the rural sanitation service coverage was much lower (WHO, 2014a). Pro-poor policies or affordability measures can be applied across both water and wastewater tariffs. According to the GLAAS survey, more than 60% of countries indicated that affordability schemes for sanitation are in place, but only in half of the cases were they widely used (WHO, 2014a).

Once the infrastructure is in place, the operation, maintenance and future capital costs are increasingly being covered through user tariffs. Full cost recovery, however, is often problematic. In low- and middle-income countries, it is more common that sanitation operation and maintenance costs are covered by government subsidies (WHO, 2014a). Alternatively, if insufficient government subsidies are forthcoming, the

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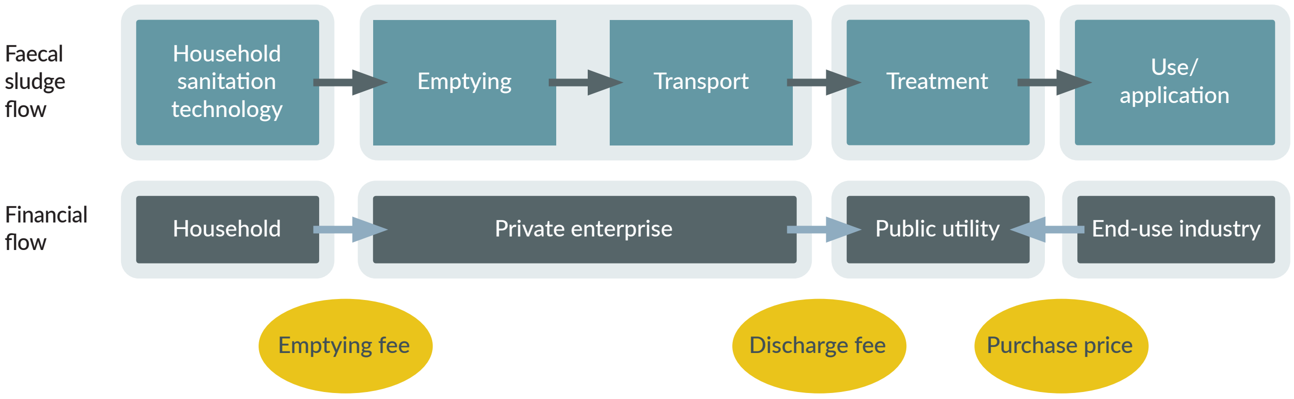
[3] TrackFin: Tracking financing to sanitation, hygiene and drinking water. For further information, see http://www.who.int/water_sanitation_health/monitoring/investments/trackfin/en/

Figure 3.2 Financial flow model for faecal sludge management



Source: Strande et al. (2014, Fig. 13.3, p. 279).

lack of financing may lead to deferred maintenance, faulty operations and system deterioration.

The benefits to society of managing human waste are considerable, both for public health and the environment. For every US$1 spent on sanitation, the estimated return is US$5.5 (Hutton and Haller, 2004). Although often difficult to measure in monetary terms, it is important to acknowledge and identify ways to assess these wider social and environmental benefits, and to funnel financial resources into the realization of such investments (UNEP, 2015b).

The potential economic and environmental benefits from wastewater use are substantial (UNEP, 2015b), but it may be difficult to finance such projects through tariffs, since users in most urban areas are charged for drinking water, sewerage and wastewater treatment in one bill (so it is not possible to pay just for one service and not for the others) and the benefits are difficult to capture in monetary terms. Hence, most water reuse projects rely on tax-financed subsidies (Molinos-Senante et al., 2011).

When it comes to nutrient recovery through FSM, several business models are feasible (see Chapter 16). Figure 3.2 shows a simple one, where a utility achieves full cost recovery through discharge fees and revenues from selling treated faecal sludge (Strande et al., 2014).

The cost-benefit analysis (CBA) is the most widely used and accepted tool for economic analysis for project evaluation. An analysis of the cost of no action versus the cost of action is useful for evaluating the economic benefits of investing in wastewater (UNEP, 2015b). Guest et al. (2009) emphasize the importance of early stakeholder involvement in any decision-making to ensure acceptance of proposals, independently of any evidence of economic benefits or cost savings.

3.4 Socio-cultural aspects

Involving citizens in decision-making at all levels promotes engagement and ownership. This includes decisions as to what types of sanitation facilities are desirable and acceptable, and how they can be securely funded and maintained in the future (see Table 3.1). It is especially important to reach out to marginalized groups, ethnic minorities, people living in extreme poverty in remote rural areas or in informal urban settlements, and to engage with women who will bear the brunt of the health consequences in case of unsafe management of human waste.

Public perception influences decision-making and limits what is possible to implement, especially when it comes to water reuse. Sometimes, economically rational reuse options are not viable, for example because of the perception that faecal material may still be present in potentially insufficiently treated wastewater. Hence, it is important to consider which uses are safe, appropriate and acceptable with which type of water. Perceptions, risk awareness and gendered divisions of labour are also important determinants for how people will protect their own and others' health in relation to wastewater use in food production (see Box 2.2).

Additionally, policy implementation can involve complex socio-political problems. Corruption is common in water and wastewater services, partly due to the monopoly position of providers and the frequency of large-capital projects (Transparency International, 2008). With regard to pollution permits and monitoring and enforcement, the incentives for corrupt practices are rife, and 'turning a blind eye' allows the problem to persist. Where corruption is common, it will be important to advocate for impartiality in regulatory enforcement (Rothstein and Tannenberg, 2015).

Integrity in the process of water resources management can be promoted by building systems that are more resistant to corruption. By enhancing transparency, accountability and participation in the sector, the opportunities for corruption can be reduced (UNDP WGF at SIWI/Cap-Net/Water-Net/WIN, 2009; WIN, 2016).

CHAPTER 4

WWAP | Angela Renata Cordeiro Ortigara and Richard Connor

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TECHNICAL ASPECTS of WASTEWATER

Aerial view of biogas plant for sewage treatment

This chapter summarizes, for the non-water specialist, some basic technical aspects about the different sources of wastewater, the potential impacts of inappropriate treatment, collection and treatment technologies, and data and information needs.

4.1 Wastewater sources and components

There is an often-cited statistic that wastewater is roughly composed of 99% water and 1% suspended, colloidal and dissolved solids (see for example UN-Water, 2015a). Although the exact composition of wastewater obviously varies between different sources and over time, water remains, by far, its principal constituent. Different sources of wastewater can present other types of components in varying concentrations (see Table 4.1).

Domestic and municipal wastewater is likely to contain high bacterial loads, though most of the bacteria present in human faeces are not inherently pathogenic. However, when an infection occurs, a large number of pathogenic microorganisms (such as bacteria, viruses, protozoa and helminths) are spread in the environment through faeces. In order to reduce the disease burden, the removal of pathogens is often the primary objective of wastewater treatment systems.

Wastewater from industrial and mining activities, as well as from solid waste management (e.g. landfill leachate), may also contain toxic organic compounds such as hydrocarbons, polychlorinated biphenyls (PCBs), persistent organic pollutants (POPs), volatile organic compound (VOCs) and chlorinated solvents. Very small amounts of certain organic compounds can contaminate large volumes of water. One litre of gasoline, for example, is enough to contaminate one million litres of groundwater (Government of Canada, n.d.).

'Emerging pollutants' (see Box 4.1) can be defined as "any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause adverse ecological and (or) human health effects" (USGS, n.d.). The main categories of emerging pollutants present in wastewater are pharmaceuticals (e.g. antibiotics, analgesics, anti-inflammatory drugs, psychiatric drugs, etc.), steroids and hormones (i.e. contraceptive drugs), personal care products (e.g. fragrances, sunscreen agents, insect repellents, microbeads and antiseptics), pesticides and herbicides, surfactants and surfactant metabolites, flame retardants, industrial additives and chemicals and plasticizers and gasoline additives. Emerging pollutants are rarely controlled or monitored and further research is needed to assess their impacts on human health and the environment. It is possible to reduce/mitigate the use and release of certain types of emerging pollutants through government regulation (see Box 4.2) and private sector engagement.

BOX 4.1 EMERGING POLLUTANTS

Emerging pollutants are found in varying concentrations in treated and untreated municipal wastewater, industrial effluents and agricultural runoff that seeps into rivers, lakes and coastal waters (UNESCO, 2011). They have also been detected in drinking water (Raghav et al., 2013), as conventional wastewater treatment and water purification processes are not effective in removing them. Advanced wastewater treatment technologies (membrane filtration, nanofiltration, ultrafiltration and reverse osmosis) can partially remove some chemicals and pharmaceutically active compounds (González et al., 2016). Potential human health risks of emerging pollutants through exposure via drinking water, as well as via agricultural products, remain a concern.

The effects of individual pollutants on human and ecosystem health have been only marginally evaluated, whereas the cumulative effects have not been studied at all. There is scientific evidence that many chemicals recognized as emerging pollutants can potentially cause endocrine disruption in humans and aquatic wildlife (causing birth defects and developmental disorders, and affecting fertility and reproductive health), even at very low concentrations (Poongothai et al., 2007), as well as cancerous tumours and the development of bacterial pathogen resistance, including multi-drug resistance.

Source: Adapted from Muñoz et al. (2009).

Contributed by Sarantuyaa Zandaryaa (UNESCO-IHP).

Table 4.1 Advantages and disadvantages of selected types of wastewater treatment systems

Sources of wastewater	Typical components
Domestic wastewater	Human excreta (pathogenic microorganisms), nutrients and organic matter. May also contain emerging pollutants (e.g. pharmaceuticals, drugs and endocrine disruptors)
Municipal wastewater	Very wide range of contaminants, such as pathogenic microorganisms, nutrients and organic matter, heavy metals and emerging pollutants
Urban runoff	Very wide range of contaminants, including incomplete products of combustion (e.g. polycyclic aromatic hydrocarbons and black carbon/soot from fossil fuel combustion), rubber, motor oil, heavy metals, non degradable/organic trash (especially plastics from roads and parking lots), suspended particulate and fertilizers and pesticides (from lawns)
Agricultural runoff (surface flow)	Pathogenic microorganisms, nutrients from fertilizers applied to the soils, and pesticides and insecticides derived from the agricultural practices
Livestock production	Organic loadings (often very high) and veterinary residues (e.g. antibiotics and artificial growth hormones)
Land-based aquaculture	Effluents from settlement ponds are typically rich in organic matter, suspended solids (particulates), dissolved nutrients, and heavy metals and emerging pollutants
Industrial wastewater	Contaminants depend on the kind of industry (see Table 6.4 for details)
Mining activities	Drainage from tailings, often contains suspended solids, alkalinity, acidity (needs pH adjustment) dissolved salts, cyanide and heavy metals. May contain also radioactive elements, depending on the mine activity (see Table 6.4 for details)
Energy generation	Water generated in the energy sector is often a source of thermal pollution (heated water) and usually contains nitrogen (e.g. ammonia, nitrate), total dissolved solids, sulphate and heavy metals (see Table 6.4 for details)
Landfill leachate	Organic and inorganic contaminants, with potentially high concentrations of metals and hazardous organic chemicals

Source: Based on US EPA (2015 and n.d.b.); UN (n.d.b.); Akcil and Koldas (2006); Government of British Columbia (1992); and Tchobanoglous et al. (2003).

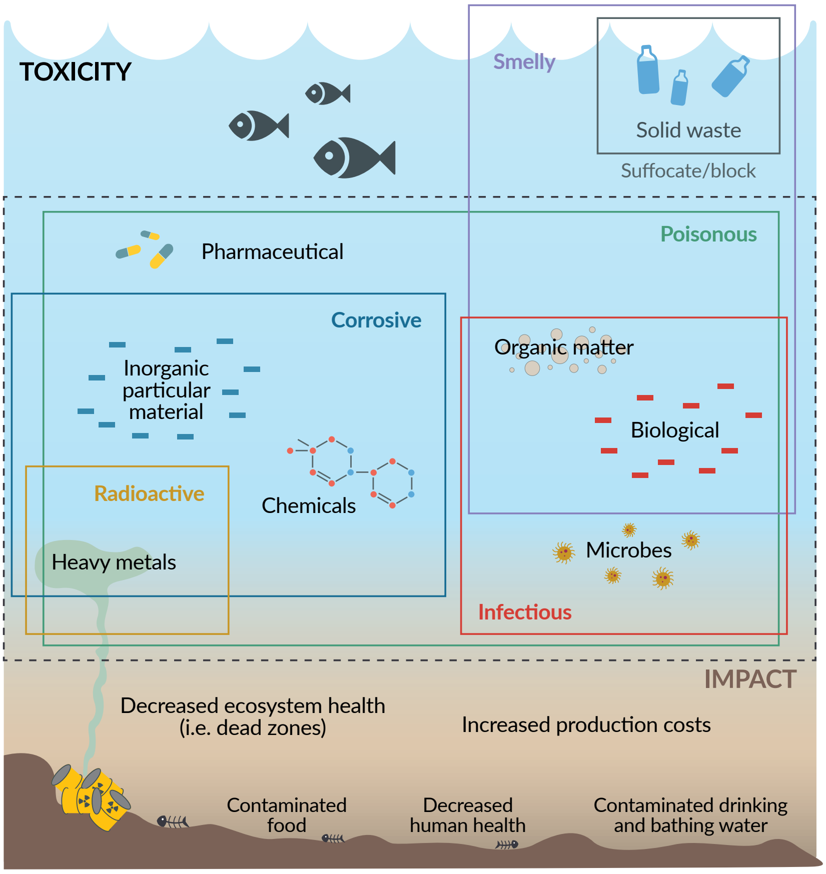
BOX 4.2 BANNING WASTEWATER CONTAMINANTS: THE EXAMPLE OF MICROBEADS

Microbeads are found in certain consumer products, such as facial cleansers and toothpaste. After use, these spherical particles made of polyethylene or polypropylene end up in wastewater. Once microbeads enter the wastewater system, few wastewater treatment facilities are able to remove them from the water streams. Risks to aquatic life and public health are not yet well understood, but the particles themselves may contain toxins or attract other toxins in the water (Copeland, 2015).

In December 2015, the US Government required US manufacturers to end the use of microbeads in products by 1 July 2017 and the sale of products containing microbeads by 1 July 2018. In June 2016, Canada added microbeads to the list of toxic substances under the Canadian Environmental Protection Act (CEPA), thus enabling the government to regulate and ban the use of microbeads (Government of Canada, 2016). In September 2016, the Government of the United Kingdom announced plans to ban microbeads in cosmetics and personal care products (DEFRA, 2016).

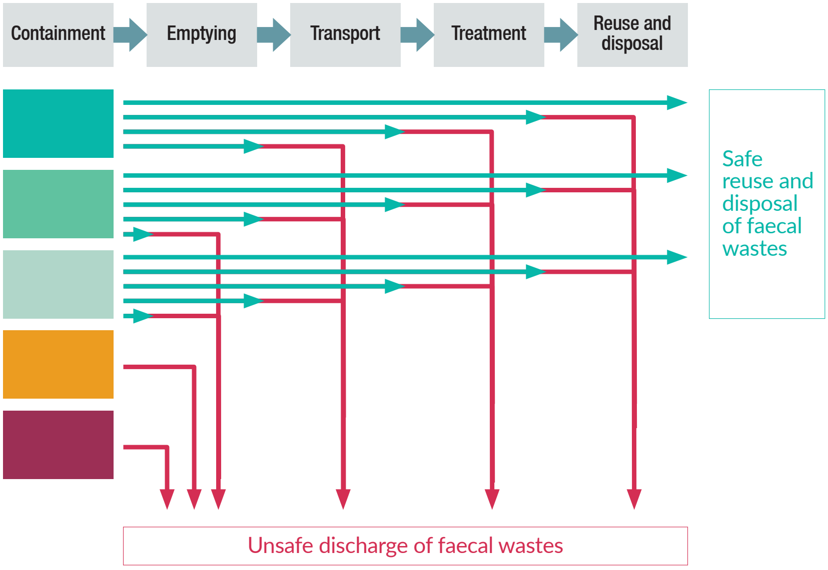
Microbeads can easily be replaced with natural ingredients like almond and apricot shells, and several large companies have already announced that they will end the use of these microplastic products. The joint action between public and private sectors effectively eliminated economic arguments for delaying a ban on these substances.

Figure 4.1 Wastewater components and their effects



Source: Adapted from Corcoran et al. (2010, Fig. 5, p. 21).

Figure 4.2 Faecal waste framework for estimating proportion of safely managed sanitation and wastewater



Source: Adapted from UNICEF/WHO (2015, Fig. 39, p. 44).

4.2 Impacts of releasing untreated or inadequately treated wastewater

The discharge of untreated or partially treated wastewater into the environment results in the pollution of surface water, soil and groundwater. Once discharged into water bodies, wastewater is either diluted and transported downstream or it infiltrates into aquifers, where it can affect the quality (and therefore the availability) of freshwater supplies. The ultimate destination of wastewater discharged into rivers and lakes is often the ocean.

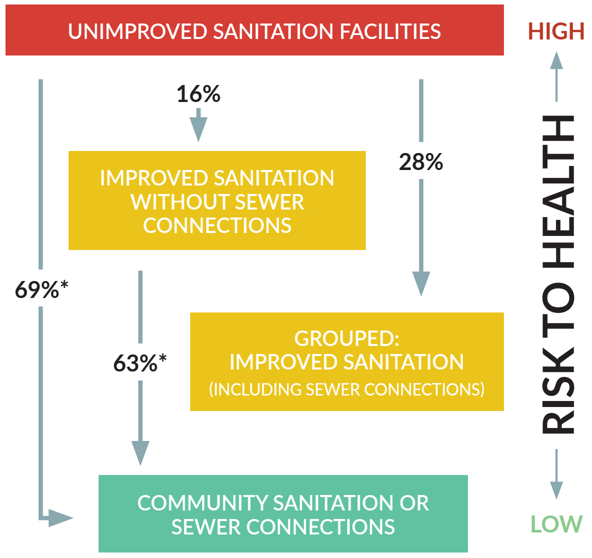
The consequences of releasing untreated or inadequately treated wastewater can be classified into three groups: adverse human health effects associated with reduced water quality; negative environmental effects due to the degradation of water bodies and ecosystems; and potential effects on economic activities (UNEP, 2015b). Figure 4.1 shows wastewater components and their effects.

4.2.1 Human health effects

Even though household sanitation facilities have increasingly been improved since 1990, risks to public health remain due to poor containment, leakages during emptying and transport, and ineffective sewage treatment (see Figure 4.2). It is estimated that only 26% of urban and 34% of rural sanitation and wastewater services effectively prevent human contact with excreta along the entire sanitation chain and can therefore be considered safely managed (Hutton and Varughese, 2016).

Sanitation and wastewater-related diseases remain widespread in countries where the coverage of these services is low, where informal use of untreated wastewater for food production is high, and where reliance on contaminated surface water for drinking and recreational use is common. In 2012, an estimated 842,000 deaths in middle- and low-income countries were caused by

Figure 4.3 Sanitation transitions and associated reductions in diarrhoeal disease



*These estimates are based on limited evidence and should therefore be considered as preliminary, and have not been used in the current burden of disease estimate.

Source: *WHO (2014b, Fig. 11, p. 12).*

contaminated drinking water, inadequate handwashing facilities, and inappropriate or inadequate sanitation services (WHO, 2014b).

Improving sanitation and wastewater treatment is also a key intervention strategy to control and eliminate many other diseases, including cholera and some neglected tropical diseases (NTDs), such as dengue fever, dracunculiasis, lymphatic filariasis, schistosomiasis, soil-transmitted helminths and trachoma (Aagaard-Hansen and Chaignat, 2010). Access to improved sanitation facilities can contribute significantly to the reduction of health risks (see Figure 4.3), and further health gains may be realized through the provision of safely managed sanitation services and safely treated wastewater.

4.2.2 Environmental effects

The discharge of untreated wastewater into the environment has an impact on water quality, which in turn affects the amount of water resources available for direct use. Concerns over water quality are rising as an important dimension of water security worldwide (see Prologue). Since 1990, water pollution has been increasing in most rivers in Africa, Asia and Latin America, due to the increasing amounts of wastewater as a result of population growth, increased economic activity and expanding agriculture, as well as the release of sewage with no (or only minimal levels of) treatment (UNEP, 2016). Inadequate wastewater management has also a direct impact on ecosystems and the services they provide (Corcoran et al., 2010) (see Chapter 8).

Eutrophication, driven by excess nitrogen and phosphorus, can lead to potentially toxic algal blooms and declines in biodiversity. The discharge of untreated wastewater into seas and oceans partially explains why de-oxygenated dead zones are rapidly growing: an estimated 245,000 km^2 of marine ecosystems are affected, and this affects fisheries, livelihoods, and food chains (Corcoran et al., 2010).

4.2.3 Economic effects

As the availability of freshwater is critical to sustaining the economic welfare of any human community, poor water quality constitutes an additional obstacle to economic development. Poor water quality hampers agricultural productivity in rural and peri-urban settings. Contaminated water can directly affect economic activities that use water, such as industrial production, fisheries, aquaculture and tourism (UNEP, 2015b), and can indirectly limit the export of certain goods due to restrictions (and even bans) on contaminated products.

For example, in the Caribbean, many small island economies are almost entirely dependent on the health of their reefs for tourism, fisheries and shoreline protection (Corcoran et al., 2010), but these reefs are threatened by the discharge of untreated wastewater. While pollution of natural environments may hinder economic activities, tourism itself and

> When the discharge of wastewater causes environmental damages, external costs (externalities) are generated and the potential benefits of using wastewater are lost

the growing demand for environmentally friendly facilities can provide leverage for investments in the maintenance of natural environments, and therefore act as an additional motivating factor for improved wastewater management.

When the discharge of wastewater causes environmental damages, external costs (externalities) are generated and the potential benefits of using wastewater are lost. An economic argument for improved wastewater management can be made in order to minimize the negative impacts it can cause and to maximize the benefits it can generate. If wastewater is recognized as an economic good, appropriately treated wastewater can have a positive value to both those producing it and those consuming it (UNEP, 2015b).

4.3 Wastewater collection and treatment

While opportunities for enhancing wastewater collection and treatment systems are discussed in Chapter 15, this section describes the basic processes from a more technical point of view. There are essentially two types of wastewater collection and treatment systems:

- **Off-site systems**, where waste is transported through a sewerage network to a treatment plant or disposal point.
- **On-site systems,** where waste is accumulated in a pit or septic tank. This tank can be periodically emptied or a new pit/septic tank can be opened in another location. Certain on-site systems have leaching beds that infiltrate the partiality treated water from septic tanks into the ground (old and overstressed systems are a significant cause of pollution in some areas). In the case of emptying, waste is transported for treatment and/or disposal. On-site systems can also include small-scale sewerage systems that convey wastewater to treatment plants located nearby.

Wastewater generated in industries can be treated on-site or released to municipal systems, but it is necessary that discharge permissions have been granted and that quality limits are being respected. Wastewater generated in the agricultural sector (e.g. livestock production, green houses), if collected and treated, can be used within the establishment for irrigation or other purposes.

Figures 4.4 and 4.5 show wastewater management systems in Kampala (Uganda) and Dhaka (Bangladesh), respectively, illustrating how they can differ among countries. The illustrations also reveal the urgent need to improve the efficiency of wastewater management systems in order to increase the proportion of wastewater that is safely managed.

4.3.1 Wastewater collection

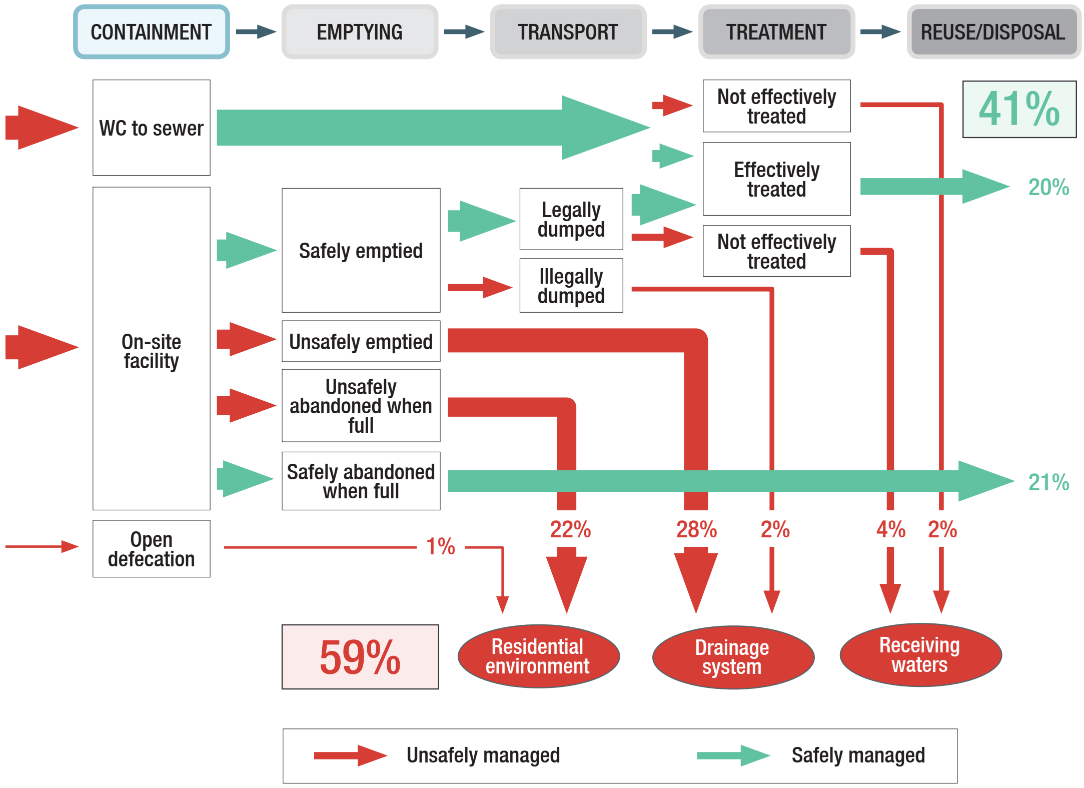
The sewerage network used for wastewater transportation can be separated or combined. In separate systems, different sets of pipes are used to transport the sewage and urban runoff, while in combined systems both flows are conveyed together. Properly installed, operated and controlled, separate systems are expected to reduce the amount of sewage to be treated, to avoid overflows, and to deal more effectively with periodic and potentially large volumes of urban runoff occurring under storm conditions. However, separate sewers do not always operate as efficiently as expected, for example when insufficient controls favour illegal sewage connections to the runoff pipelines.

The endpoint of a sewerage network should be a treatment plant, which aims to remove contaminants from wastewater so that it can be either safely used again (fit-for-purpose treatment) or returned to the water cycle with minimal environmental impacts.

Wastewater treatment can follow a centralized or decentralized approach. In centralized systems, wastewater is collected from a large number of users, like an urban area, and treated at one or more sites. Collection costs account for over 60% of the total budget for wastewater management in a centralized system, particularly in communities with low population densities (Massoud et al., 2009).

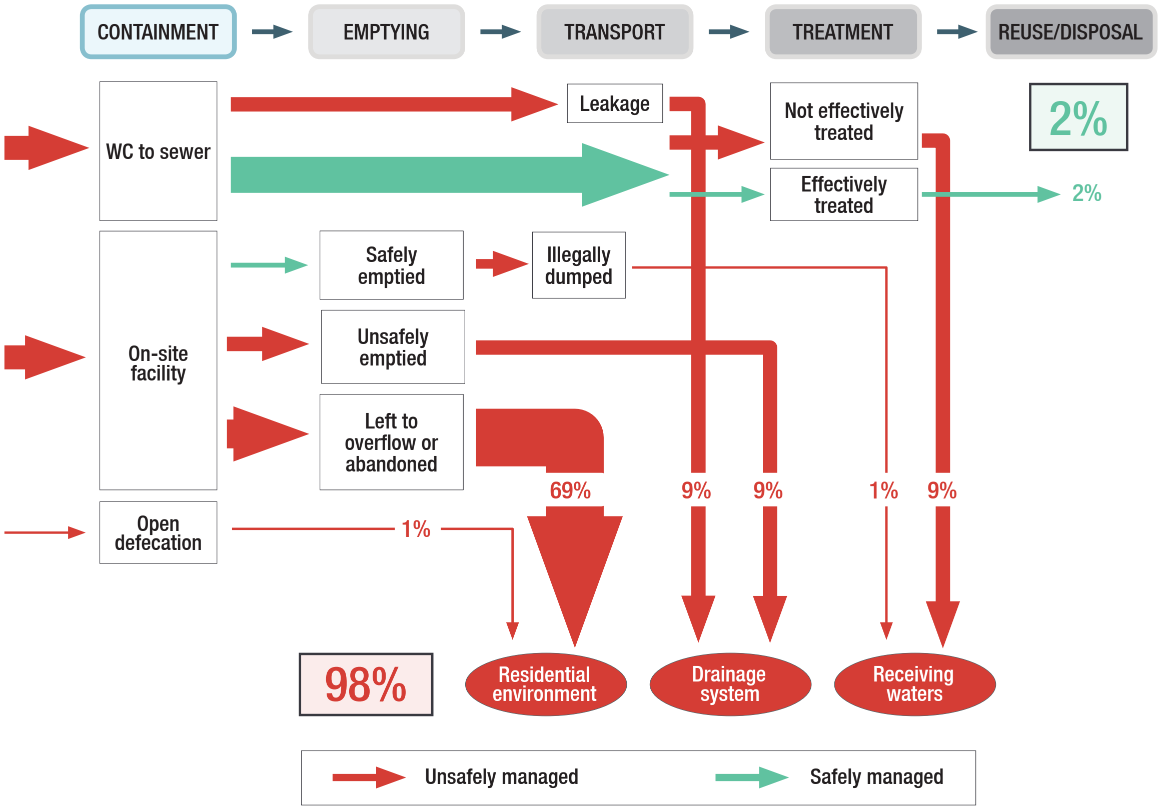
Decentralized systems employ a combination of on-site and/or cluster systems for wastewater treatment, and are often used for individual houses, scattered and low-density communities, and rural areas. Even though decentralized treatment systems often reduce collection costs, they may not provide the same level of benefits and still require a level of operation and maintenance as effective as in centralized systems.

Figure 4.4 Water management system in Kampala (Uganda)



Source: *Peal et al. (2014, Fig. 6, p. 571).*

Figure 4.5 Water management system in Dhaka (Bangladesh)



Source: *Peal et al. (2014, Fig. 4, p. 570).*

> **Emerging pollutants are rarely controlled or monitored and further research is needed to assess their impacts on human health and the environment**

4.3.2 Wastewater treatment

Wastewater treatment consists of a combination of physical, chemical, and biological processes to remove wastewater constituents.

Physical processes enable the removal of substances by the use of natural forces (i.e. gravity) as well as physical barriers, such as filters and membranes or ultraviolet (UV), which are mainly used for disinfection. The use of membranes is increasing because of the high quality of effluent after treatment and for the effective removal of organic micro-pollutants, from pesticides to pharmaceuticals and personal care products (Liu et al., 2009). Membrane systems are characterized by high energy consumption and high levels of operation and maintenance (Visvanathan et al., 2000).

Chemical processes are often used for disinfection and for the removal of heavy metals. Chemically assisted primary treatment, for example using ferric salts or polyelectrolyte, can remove BOD and solids, but the sludge generated is often difficult to treat and dispose of (UN-Water, 2015a). Chemically advanced oxidation has been shown to remove endocrine-disrupting compounds (EDCs) (Liu et al., 2009).

Biological processes in wastewater treatment reproduce the degradation that naturally occurs in rivers, lakes and streams. These processes are used in wastewater treatment plants where biological reactors are engineered to boost biochemical degradation under carefully controlled conditions, therefore enhancing the removal of pollutants and the stabilization of sludge.

The processes taking place in the bioreactors can be aerobic or anaerobic. The former often needs more energy in order to maintain the aerobic conditions inside the reactor, and the organic waste is converted into biomass (sludge) and carbon dioxide (CO_2). However, it prevents the formation of methane (CH_4), which has a greater climate warming potential than CO_2 (Cakir and Stenstrom, 2005). Anaerobic treatment processes generally require less energy and have a lower sludge production and generates CH_4, but this can be captured and used as an energy source.

Physical, chemical and biological processes are combined to achieve different 'levels' of wastewater: preliminary, primary, secondary, tertiary and quaternary (see Lexicon for a more detailed description).

The selection of the most appropriate technologies depends on the kind of components, pollution load, anticipated use of the treated wastewater and economic affordability. Table 4.2 provides some examples of technologies, the kind of wastewater they are generally used for, and their advantages and disadvantages.

One of the by-products of wastewater treatment is sewage sludge. The sludge generated is rich in nutrients and organic matter, which gives it considerable potential for use as a soil conditioner and fertilizer (see Chapter 16). In many cases, however, the beneficial value of sewage sludge is not realized because of concerns regarding the pathogens, heavy metals and other compounds it may contain. Other useful by-products from wastewater include biogas (i.e. CH_4) and heat, which can be recovered for beneficial use either in the treatment plant or in the adjacent community.

The actual management and operation of wastewater treatment systems is a complex activity that can benefit from a risk assessment approach that evaluates the chain of components that together make up the system. Such assessments can help ensure their proper functioning under expected levels of efficiency, and highlight weak links in the chain that could cause health and safety issues (see Box 4.3).

4.4 Data and information needs

Data on wastewater collection and treatment are sparse, particularly (but not only) in developing countries. According to Sato et al. (2013), only 55 out of 181 analysed countries had reliable statistical information on generation, treatment, and use of wastewater, 69 countries had data on one or two aspects, and 57 countries had no information at all. Moreover, data from approximately two thirds (63%) of the countries were over five years old. FAO's main AQUASTAT database has a section on municipal wastewater, where wastewater-related information can be found under the 'water resources' and the 'water use' sections of each country profile. However, some of this data may be over five years old.

The key challenge with data collection relates to the need of generating data at the national level that it is sufficiently detailed, consistent and comparable with other countries.

The GLAAS, a UN-Water initiative implemented by WHO, provides country profiles on sanitation and drinking water coverage. The GLAAS also contains information on topics related to governance, monitoring water data and human resources. Starting with the 2016/2017 reporting cycle, financing will also be included, which might unveil additional information on some aspects of wastewater management.

The United Nations Statistical Division (UNSD) is responsible for developing fundamental principles of official statistics to guide the work of national statistics agencies. In 2012, it adopted the System of Environmental-Economic Accounting – Central Framework (SEEA-CF), which includes the System of Environmental-Economic Accounting for Water (SEEA-Water). SEEA-Water proposes a conceptual framework for understanding the interactions between the economy and the environment, and addresses water data needs (UNSD, 2012). SEEA-Water includes standardized tables to be completed by countries on financial expenditures for wastewater management, including measurement of wastewater flows within the economy.

There are other global efforts to enhance data collection related to wastewater at the regional level. OECD and Eurostat conducted a joint survey on inland waters that included questions on the capacity of wastewater treatment plants, and the production of sludge and chemical emissions from industry, agriculture and human settlements (Eurostat, 2014). UNSD and UNEP conduct a biennial environmental data collection campaign in all countries, except those that are covered by the Joint OECD/Eurostat survey. The UNSD/UNEP survey acquires statistics on renewable freshwater resources, freshwater abstraction and use, wastewater generation and treatment, and the population served by wastewater treatment (UNSD, n.d.). Data on the general characteristics and quality of industrial waste and wastewater can be found within the countries' Pollutant Release and Transfer Registries (PRTRs) (see Chapter 14).

Beyond information on the generation, treatment and use of wastewater, an examination of the wastewater management literature by UN-Water (2015a) revealed other relevant data gaps, including information on the condition of the existing wastewater infrastructure, the performance of wastewater treatment, the fate of faecal sludge, and the volume, quality and location of wastewater used in irrigation. A refined global dataset for wastewater production is under development by AQUASTAT (n.d.a.).

BOX 4.3 RISK ASSESSMENT IN THE MANAGEMENT OF WASTEWATER SYSTEMS

A managed wastewater treatment system often constitutes a long and multifaceted chain of interconnected components (pipes, pumps, treatment facilities, etc.). Assessing and managing the risks involved in these components requires techniques that are similar to those employed in environmental impact assessments, health and safety assessments and asset management. The objective is to identify potential risks (which can be classified according to nature, severity, likelihood of occurrence, consequences, etc.), and implement control measures for each one.

A 'follow the flow' process is usually a good way to proceed. This starts with making an inventory of the type of pollutants (physical/chemical/bacteriological composition, etc.), their concentration, and the likely frequency of their occurrence/discharge, which can be impacted by the meteorological conditions and the behaviour of the polluter. This step is essential for identifying and predicting impacts and events throughout the chain of components.

Each link in the chain (both assets and processes) then needs to be examined in order to determine how it should function, how it could malfunction, how it could interact with the pollutant, what the impacts of the malfunction would be, how long it would take to solve a malfunction, and so on. Some malfunctions can occur due to interactions between the pollutant and the infrastructure. For example, many pollutants can cause corrosion of pipes and equipment, or block and jam pumps. Others can arise from 'external' events, such as electrical failure, traffic damage or vandalism.

There are also a considerable number of health and safety risks that can affect both operational personnel and the general public. These range from the risks of drowning to the release of dangerous gases, from physical injury to long-term diseases. At the end of the chain are the points of discharge, beyond which the sensitivity of downstream users – either the natural environment or other water users – also needs to be assessed. The effectiveness and image of the wastewater management can be seriously impacted if the interests of these downstream users are not properly taken into account in the risk assessment process.

An effective risk assessment process normally requires several different and complementary skills to be conducted in an appropriate manner.

Contributed by Jack Moss (AquaFed).

Table 4.2 Advantages and disadvantages of selected wastewater treatment systems

Type	Nature of wastewater	Advantages	Disadvantages	Components removed
Septic systems	Domestic wastewater	Simple, durable, easy maintenance, small area required	Low treatment efficiency; necessity of a secondary treatment; effluent not odourless; content must be removed at frequent intervals	COD, BOD, TSS; grease
Composting toilets	Human excreta, toilet paper, carbon additive, food waste	Reduce waste consumption and support the recycling of nutrients (e.g. use of resulting sludge in agriculture)	Need of proper design and maintenance in order to protect the environment and human health	Volume reduced from 10 to 30%; pathogens
Anaerobic filter	Pre-settled domestic and industrial wastewater of narrow COD/BOD ratio	Simple and fairly durable, if well constructed and wastewater has been properly pre-treated; high treatment efficiency; little land area required	Filter material can incur high construction costs; clogging of filter can occur; effluent not odourless	BOD, TDS, TSS
Anaerobic treatment (e.g. biodigestor, UASB, etc.)	Human excreta, animal and agricultural wastes	Recycling of resource; gas produced can be used for power generation, cooking and lighting	Complex operation and maintenance, which can lead to gas leakage or reduced production and blockage of the digester tank with solids; anaerobic treatment often provides little removal of nutrients	COD, BOD, TSS; grease
Stabilizations ponds Anaerobic, facultative and maturation ponds	Domestic, industrial and agricultural wastewater; good for small/medium sized towns	Maturation ponds can achieve good bacterial removal; need to be desludged at intervals – failing to do so can have serious consequences; biogas can be recovered as a source of energy	Land-intensive; sometimes high BOD and SS in effluent from algae but relatively harmless; sometimes seen as warm weather process but can be used in moderate climates	BOD, SS, TN, TP
Duckweed-based wastewater stabilizations ponds	Domestic and agricultural wastewater	No clogging risk; high nutrient removal rates	Land-intensive; necessity of constant harvesting; unsuitable in very windy regions	BOD, SS, TN, TP, metals
Constructed wetlands	Domestic and agricultural wastewater; small communities; tertiary treatment for industries	Low or no energy requirements; low maintenance costs; provides aesthetic, commercial and habitat value	Land-intensive; clogging of the system can occur	TSS, COD, TN, TP
Aerobic biological treatment (i.e. activated sludge)	Domestic and industrial wastewater Aerators made from stainless steel are resistant to corrosive wastewater, making them suitable for industrial pulp and paper plants, chemical industry and other rough environments	Good removal of BOD, and the plant can be operated to facilitate N and P removal Rapid, economic compared to other methods, odour-free	High maintenance requirements; ineffective in deep water (therefore, basins are generally shallow) and under freezing weather conditions Little removal of bacterial loads and high sludge production	BOD, SS, TN, TP.
Membrane system Microfiltration, ultrafiltration, nanofiltration, RO	Pre-settled wastewater; can be used in combination with biological processes (MBR, MBBR)	Processes that close the water cycle and produce high-purity water for reuse	Higher costs and higher requirements in operation, maintenance and power consumption	Microfiltration and ultrafiltration eliminate all biological agents and macromolecules; nanofiltration removes simple organic molecules; RO removes inorganic ions

BOD Biological oxygen demand – **COD** Chemical oxygen demand – **MBBR** Moving bed biofilm reactor – **MBR** Membrane biological reactors – **RO** Reverse osmosis– **SS** Suspended solids – **TDS** Total dissolved solids – **TN** Total nitrogen – **TP** Total phosphorus – **TSS** Total suspended solids – **UASB** Upflow anaerobic sludge blanket

Source: Compiled by Birguy M. Lamizana-Diallo (UNEP) and Angela Renata Cordeiro Ortigara (WWAP), based on WHO (2006) and UN-Water (2015a).

PART II

THEMATIC FOCUS

Chapter 5 | Municipal and urban wastewater

Chapter 6 | Industry

Chapter 7 | Agriculture

Chapter 8 | Ecosystems

CHAPTER 5

UN-Habitat | Graham Alabaster, Andre Dzikus and Pireh Otieno

MUNICIPAL AND URBAN WASTEWATER

Wastewater in the Klong Ong Ang Canal in Bangkok (Thailand)

This chapter discusses the sources and impacts of municipal and urban wastewater, highlighting the future prospects for wastewater production. In addition, the chapter frames the opportunities for water reuse and recycling.

Municipal wastewater originates from domestic, industrial, commercial and institutional sources within a given human settlement or community. Urban wastewater includes both municipal wastewater and urban runoff.

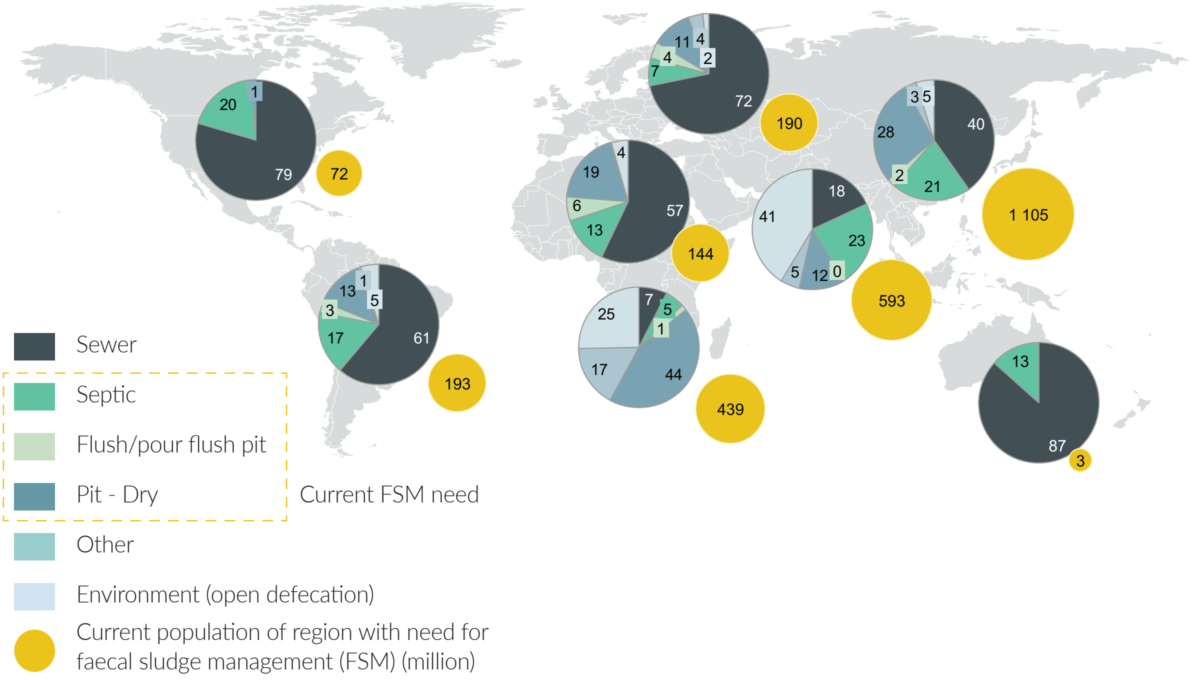
Since municipal and urban wastewater production is heavily dependent on the form and function of urban systems, the current and future patterns of urbanization must be critically examined in order to develop more sustainable approaches to wastewater management in the coming decades.

Figure 5.1 shows a breakdown of sanitation coverage by region, and hence of formal wastewater collection. It is clearly evident that sewers for wastewater collection are the favoured choice for much of the developed world, in spite of the use of on-site services in many rural areas and in areas undergoing unplanned urbanization (see Chapter 15).

5.1 Urbanization and its impact on wastewater production

Urban areas around the world are facing enormous challenges. The acceleration of urban growth, changes in family and work practices, and the expansion of informal settlements will increasingly challenge the provision of services. This is compounded by the impact of extreme events, climate change and migration in areas in conflict. Changing patterns of urbanization have resulted in more inequity, with the poor in some developed regions facing the same challenges as those from developing regions. By 2030, global demand for energy and water is expected to grow by 40% and 50%, respectively (UN-Habitat, 2016). Most of this growth will be in cities, which will require new approaches to wastewater management. At the same time, wastewater management may also provide some of the answers to other challenges, including food production and industrial development.

Figure 5.1 Percentage of population served by different types of sanitation systems



Source: Cairns-Smith et al. (2014, Fig. 8, p. 25, based on data from WHO/UNICEF JMP). Courtesy of the Boston Consulting Group.

5.2 Urban forms

The definition of rural and urban is most commonly based on national technical definitions related to geographical boundary considerations rather than population density or other defining characteristics. However, in order to understand municipal wastewater production, it is necessary to consider a further analysis of 'urban' as differing urban forms do not only produce wastewater in different ways, but also guide the potential choices for the collection, treatment and use of wastewater (see Table 5.1). Based on a review of typical urban forms, the following typologies cover most situations in developed and developing countries:

- **Large urban centres** include megacities, urban areas with a clear central business district (CBD) and well-developed suburbs with varying levels of progressively decreasing population density with increasing distance from the CBD. The large centre may be connected (or not) to smaller satellite centres by transport corridors. These cities often have extensive sewer networks, but some, like Lagos, Nigeria, are poorly served by sewer networks (see Box 5.1).
- **Large urban centres resulting from conurbations**, where two or more distinct urban centres progressively grow and see their population density increase, until they more or less merge into one metropolitan area. These areas have extensive sewer networks in developed sections of each of the former city centres, which may have formed in different ways, and often have separate treatment facilities and municipal administrations. These types of urban centres also have large unsewered areas. Examples include the Accra-Tema conurbation in Ghana or the conurbation of smaller centres in Metro Manila.
- **Smaller urban centres** typically are towns that have a small CBD, possibly some small satellites and radial linear expansion along the major routes. These smaller urban centres often have very limited sewer networks, mostly relying on on-site sanitation. They may be physically close to other centres, but they have different municipal administrations, and therefore separated institutional responsibility.
- **Large villages and small towns** are typically quite compact but differ from urban centres as they have little fringe expansion. These could also be settlements that have developed around industrial or commercial activities. Examples include college campuses, airports and mines.
- **Rural areas** are typically almost entirely served by on-site systems, without any formal sewer systems. Some urban runoff management may be practised.

BOX 5.1 SEWAGE AND WASTE DISPOSAL IN LAGOS, NIGERIA

Although Lagos State generates 1.5 million m^3 of wastewater per day (about 550 million m^3 per year), there is no central sewage system in the megacity. Less than 2% of the population is served by off-site sewage treatment plants, and only toilet wastewater is connected to septic tanks and soakaway systems. Other household liquid waste is discharged directly into the mostly open gutters in front of houses or on the streets. The wastewater eventually percolates or is washed into water bodies by rainstorms. Septic tanks and soakaway systems used in the collection of toilet wastewater often contaminate and pollute the shallow groundwater—a vital source of water to most low- and middle-income residents. Also, there is no septage treatment plant in the megacity and the untreated septage is mostly evacuated into the Lagos Lagoon, especially in areas like Iddo, Makoko, Ajegunle and other locations. The faecal contamination of the megacity's water system and the environment through the inadequate management of wastewater is an important health concern. A combination of official neglect, corruption and extreme poverty, coupled with rapid, largely uncontrolled population growth has led to the decay of Lagos' existing city infrastructure. With a current estimated population of 18 million and a 3% annual growth rate, Lagos State is expected to become home to over 23 million people by the year 2020. Concerted efforts are needed urgently to minimize further contamination of water resources.

Source: Major et al. (2011) and NLÉ (2012).

The classification of each centre is dependent on the region. In China, for example, an urban centre with a population of five million might be considered a 'small' city. In addition, each of the categories above might include slum populations. The proportion of slums tends to be greater in larger cities, due to the increased opportunities for work and the need for low-cost housing (UN-Habitat, 2016), but they also pose a challenge for smaller urban centres.

In the next one or two decades, the largest rates of urbanization will occur in the smaller urban centres of between 500,000 and 1 million inhabitants (UN-Habitat, 2016). This will greatly impact wastewater production and the potential both for decentralized treatment and use.

Table 5.1 Urban typologies and wastewater, and sustainable urban drainage issues

Urban typology	Likelihood of extensive sewer networks	Presence of on-site systems	Slum populations	Type of treatment	SUDS*	Level of wastewater production	Reuse/ recovery potential
Large urban centres	Yes	Unlikely	Extensive	Centralised/ decentralized	Optimal	High	High
Large urban centres resulting from conurbations	Yes, but not separate for each centre	Unlikely	Significant	Centralised	Optimal	High	High
Smaller urban centres	Unlikely	Likely	Possible	Decentralised or septic tank		Medium	High/ localized
Large villages and small towns	Very unlikely	Very likely	Possible	Septic tank		Small	Possible
Rural areas	Not present	Very likely	Unlikely	Centralised		Negligible	Negligible/ in-house reuse

** SUDS: Sustainable urban drainage systems*

Source: Author.

5.3 Sources of wastewater in municipal and urban systems

The composition of municipal wastewater can vary considerably, reflecting the range of contaminants released by the different combination of domestic, industrial, commercial and institutional sources.

The precise urban form and legislative/ institutional environment usually dictates how this wastewater is collected and treated (see Chapters 3, 4 and 15). However, in most countries, only a proportion of the wastewater is formally collected. A large proportion, mainly from low-income settings, is typically disposed of to the closest surface water drain or informal drainage canal.

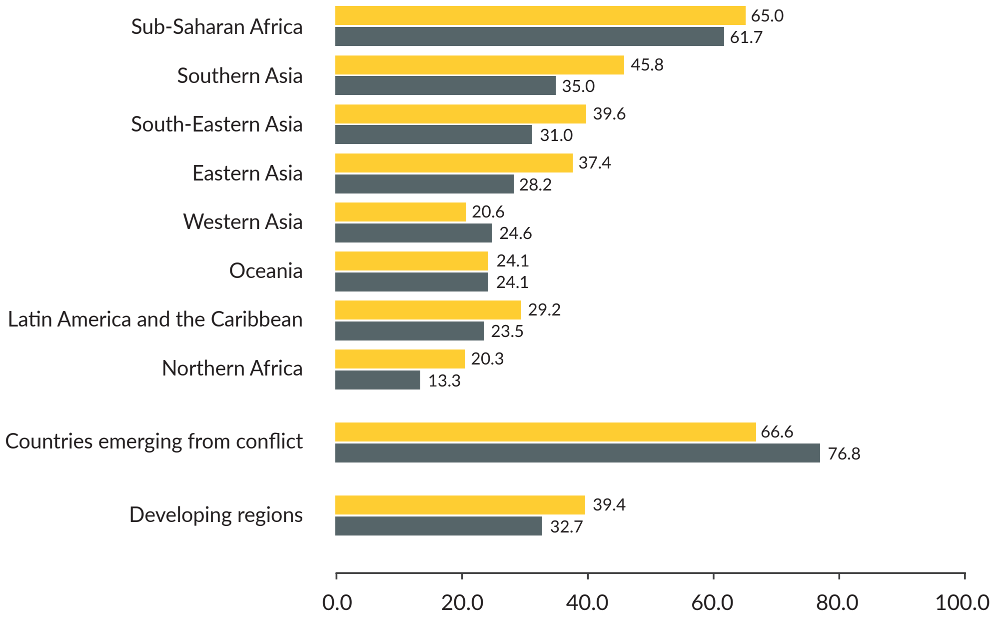
In economies that are heavily industrialized or in the process of development and where legislative environments are weak, much of the wastewater is mixed together before treatment and discharge. Where waterborne sewerage is the norm, so-called ‘combined sewerage’ remains common. This is a perfectly logical approach if large volumes of water are used for flushing, resulting in diluted sewage combined with few other wastewater sources (UN-Habitat, n.d.).

It is important to note that, in many cases, large volumes of wastewaters that are legally discharged to decaying and/or badly operated sewerage networks, both combined and separate, never actually reach a treatment plant. Much is lost en route as a result of broken pipes, or ends up in surface water drains, polluting both groundwater and surface watercourses. There are also many cases of illegal water reuse by communities who deliberately tamper with trunk sewer systems.

5.3.1 Sanitation and the production of wastewater in slums

Wastewater generation is one of the biggest challenges associated to the growth of informal settlements (slums) in the developing world. Although the proportion of slum dwellers in urban areas has slightly decreased since 2000 in terms of percentages (see Figure 5.2), there are more slum dwellers in 2012 than in 2000. In Sub-Saharan African, 62% of the urban population live in slums. The most alarming statistics can be found in countries emerging from conflict and in West Asia, where the proportion living in slums has increased from 67% to 77% and 21% to 25%, respectively (UN-Habitat, 2012).

Figure 5.2 Proportion of urban population living in slums 2000–2012



Note: Countries emerging from conflicts included in the aggregate figures as: Angola, Cambodia, Central African Republic, Chad, Democratic Republic of the Congo, Guinea-Bissau, Iraq, Lao People's Democratic Republic, Lebanon, Mozambique, Sierra Leone, Somalia and Sudan.

Source: Based on data from UN-Habitat (2012, Table 3, p. 127).

Slums vary in type, form and population density. However, most are characterized by a lack of paved roads, durable housing, water and sanitation infrastructure and drainage. In these situations, high levels of faecal matter and solid waste are disposed of to surface water drainage canals and ditches. Poor solid waste disposal causes blockages in drainage systems, resulting in flooding. Uncollected wastewater and urban runoff flows are often equivalent to sewered wastewater in terms of toxicity and health risks. Although many slums rely on on-site sanitation, faecal matter is not usually contained and wastewater is still produced as residents often use latrines as bathrooms for personal ablutions with so-called 'bucket showers'.

Slum dwellers frequently have to rely on unsewered communal public toilets, use open space or dispose of faeces in polythene bags (i.e. flying toilet). Communal toilets are not widely used, due to lack of water, poor maintenance, and the cost to the user. A study in the slums of Delhi found that the average low-income family of five could spend 37% of its income on communal toilet facilities (Sheikh, 2008). Finding a suitable place to go to the toilet is especially problematic for women, causing risks related to personal security, embarrassment and hygiene.

5.4 Composition of municipal and urban wastewater

The precise composition of wastewater varies around the world and is governed by a wide range of factors, including domestic water use and the level of commercial/industrialization. Table 5.2 gives selected parameters (UN-Water, 2015a). In developed regions, the BOD:COD ratio[4] is likely to be lower than in the developing world, due to a higher proportion of industrial wastewater. This will lower the water's suitability for biological treatment. In some areas, high levels of inorganic substances, sulphates and alkalinity for example, can affect the wastewater's suitability for post-treatment use. Sulphates tend to result in

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[4] **Biochemical oxygen demand** (BOD) is the amount of dissolved oxygen needed (i. e., demanded) by aerobic biological organisms to break down organic material present in a given water sample at a certain temperature over a specific time period.

Chemical oxygen demand (**COD**) is the standard method for indirect measurement of the amount of pollution (that cannot be oxidized biologically) in a sample of water. The higher the chemical oxygen demand, the higher the amount of pollution (mostly inorganic) in the test sample.

If the **BOD:COD ratio** for untreated wastewater is 0.5 or greater, the waste is considered to be easily treatable by biological means. If the **ratio** is lower than 0.3 approximately, either the waste may have some toxic components, or acclimated microorganisms may be required for its stabilization.

Table 5.2 Composition of raw wastewater for selected countries

Parameters	USA	France	Morocco	Pakistan	Jordan
Biochemical oxygen demand	110–400	100–400	45	193–762	152
Chemical oxygen demand	250–1 000	300–1 000	200	83–103	386
Suspended solids	100–350	150–500	160	76–658	n.a.
Total potash and nitrogen	20–85	30–100	29	n.a.	28
Total phosphorus	4–15	1–25	4–5	n.a.	36

Source: UN-Water (2015a, Table 5, p. 28, based on Hanjra et al., 2012).

Table 5.3 Main wastewater pollutants, their source and effects

Pollutant	Main representative parameters	Source				Possible effects of the pollutant
		Wastewater		Runoff		
		Domestic	Industrial	Urban	Agricultural and pasture	
Suspended solids	Total suspended solids	xxx	← →	xx	x	• Aesthetic problems • Sludge deposits • Pollutant adsorption • Protection of pathogens
Biodegradable organic matter	Biochemical oxygen demand	xxx	← →	xx	x	• Oxygen consumption • Death of fish • Septic conditions
Nutrients	Nitrogen, Phosphorus	xxx	← →	xx	x	• Excessive algae growth • Toxicity to fish (ammonia) • Illness in new-born infants (nitrate) • Pollution of groundwater
Pathogens	Coliforms	xxx	← →	xx	x	• Water-borne diseases
Non-biodegradable organic matter	Pesticides, some detergents, others	x	← →	x	xx	• Toxicity (various) • Foam (detergents) • Reduction of oxygen transfer (detergents) • Non-biodegradability • Bad odour (i.e. phenols)
Metals	Specific elements (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, etc.)	x	← →	x		• Toxicity • Inhibition of biological sewage treatment • Problems in agriculture use of sludge • Contamination of groundwater
Inorganic dissolved solids	Total dissolved solids, conductivity	xx	← →		x	• Excessive salinity – harm to plantations (irrigation) • Toxicity to plants (some ions) • Problems with soil permeability (sodium)

x: small **xx**: medium **xxx**: high **arrows**: variable **empty**: usually not important

Source: Von Sperling (2007, Table 1.2, p. 7).

Table 5.4 Red List Substances

1	1.2-dichloroethane [1.2-DCE or EDC]
2	Aldrin
3	Atrazine
4	Azinphos methyl
5	Cadmium
6	DDT isomers
7	Dichlorvos
8	Dieldrin
9	Endrin
10	Fenitrothion
11	Hexachlorobenzene [HCB]
12	Hexachlorobutadiene [HCBD]
13	Hexachlorocyclohexane [HCH]
14	Malathion
15	Mercury
16	Pentachlorophenol [PCP]
17	Polychlorinated biphenyl [PCB]
18	Simazine
19	Tributyltin [TBT]
20	Trichlorobenzene [TCB]
21	Trifluralin
22	Triphenyltin [TPT]

Source: Environment Agency (2009, p. 4).

hydrogen sulfide production with implications for sewer corrosion. High alkalinities, or water hardness, are likely to cause limescale deposits and will affect the suitability of the water for reuse as process water, for example. Table 5.3 gives some of the main pollutants that are likely to be found in different sources of wastewater (see also Table 4.1).

5.4.1 Wastewater from particularly hazardous sources

Wastewater from domestic sources is usually relatively free from hazardous substances, but there are growing concerns about commonly used medications that, even at low concentrations, may have long-term impacts: some known endocrine disrupters in particular (Falconer, 2006).

Industries that use 'Red List' substances (see Table 5.4) in their production processes are required to ensure that discharge consents are adhered to, but this is often not the case. Regulatory environments vary considerably. Of particular relevance are small-scale cottage industries and businesses, which are either 'permitted' to operate or do so illegally. In informal settings, activities, such as lead recovery from batteries, small-scale mining and mineral processing, and the operation of motor garages and car-washing stations can pose serious risks. There is not much published information available concerning these informal industries.

Small hospitals and clinics (and some of the larger establishments), particularly in the developing world, discharge medical waste untreated. Intensive farming methods and the profligate use of antibiotics in animal husbandry has resulted in high concentrations in municipal wastewater when such installations discharge to municipal sewers. This entails the additional risk of antimicrobial drug resistance (AMR) (Harris et al., 2013).

Other point sources can include intensive agricultural units and large stormwater outlets that serve hazardous or industrial areas. Table 5.5 gives estimated figures of wastewater production for commercial establishments and industries. Although not shown in this table, it is important to note that wastewater from food and beverage processing establishments also generally contain relatively high BOD concentrations. This type of waste is not difficult to treat and represents a great opportunity for energy recovery (see Chapter 6).

5.5 Urban form and the potential for municipal and urban wastewater use

The potential for using municipal and urban wastewater is governed by several issues: first, the level of cross-contamination of wastewater and second, the application and its location. Water scarcity and the cost and availability of new water sources are also important factors. Obviously, it is better to restrict the discharge of hazardous substances to sewers, particularly those that render the wastewater difficult to treat. Urban runoff, for example, could be directly reused for certain purposes, but once combined with blackwater it would require additional treatment.

The drivers for reuse are legislative and principally driven by economics. If used water is available at a lower or a similar price (including the cost of conveyance), it will be considered over and above conventional freshwater sources. In some water-scarce countries or regions, necessity dictates and favours high levels of reuse.

BOX 5.2 INDIRECT POTABLE REUSE IN PRACTICE, SAN DIEGO, CALIFORNIA

San Diego is drinking recycled water because it imports 85% of its water from Northern California and the Colorado River, into which upstream communities like Las Vegas discharge wastewater that is later treated for drinking purposes. San Diego, which recycles sewage water for irrigation, invested US$11.8 million into an IPR study, because of recent restrictions on Northern California water and drought in the Colorado River. The demo project at the North City Water Reclamation Plant ended in 2013. At that time, its Advanced Water Purification Facility was producing one million gallons of purified water each day, though no water is being sent to the reservoir.

IPR is more economical for San Diego than recycling more sewage for irrigation because irrigation water would have to be conveyed through special purple pipes to separate it from potable water, and expanding the purple pipe infrastructure would cost more than IPR. Recycled water is also less expensive than desalinating seawater. In Orange County, for example, IPR costs US$800–850 to produce enough drinking water for two families of four for a year. Desalinating an equal amount of seawater would require US$1,200–1,800 because of the amount of energy needed.

To deal with its growing population and salt intrusion into the groundwater, the Orange County Water District in California opened its US$480 million state-of-the-art water reclamation facility, the largest in the U.S., in January 2008. It costs US$29 million a year to operate. After advanced water treatment, half the recycled water is injected into the aquifer to create a barrier against saltwater intrusion. The other half goes to a percolation pond for further filtration by the soils, and then after about six months, ends up in drinking water well intakes. By 2011, it was estimated to be producing over 300 million litres a day.

Source: Extracted from Cho (2011).

Table 5.5 Examples of industrial wastewater data

Industry type	Wastewater generation (m^3/tonne)	Range (m^3/tonne)	COD (kg/m^3)	COD range (kg/m^3)
Alcohol refining	24	16–32	11	5–22
Beer and malt	6.3	5–9	2.9	2–7
Coffee	n.a.	n.a.	9	3–15
Dairy products	7	3–10	2.7	1.5–5.2
Fish processing	n.a.	8–18	2.5	
Meat and poultry	13	8–18	4.1	2–7
Organic chemicals	67	0–400	3	0.8–5
Petroleum refineries	0.6	0.3–1.2	1.0	0.4–1.6
Plastic and resins	0.6	0.3–1.2	3.7	0.8–5
Pulp and paper (combined)	162	85–240	9	1–15
Soap and detergents	n.a.	1–5	n.a.	0.5–1.2
Starch production	9	4–18	10	1.5–42
Sugar refining	n.a.	4–18	3.2	1–6
Vegetable oils	3.1	1–5	n.a.	0.5–1.2
Vegetables, fruits and juices	20	7–35	5.0	2–10
Wine and vinegar	23	11–46	1.5	0.7–3.0

n.a.: Not available

Source: Doorn et al. (2006, Table 6.9, p. 622, based on Doorn et al., 1997).

BOX 5.3 SEWAGE-FED AQUACULTURE SYSTEMS OF KOLKATA: A CENTURY-OLD INNOVATION OF FARMERS

Farmers around Kolkata city in India developed a technique of using domestic sewage for fish culture and other agricultural purposes, almost a century ago. This technique is widely used to meet the growing demand for fish in this densely populated Indian city. The technique is considered to be unique and is the largest operational system in the world to convert waste into consumable products. Wastewater and urban runoff from Metropolitan Kolkata (over 13 million inhabitants) generates about 600 million litres of sewage per day. Large-scale usage of sewage for fish culture began in the 1930s. Early success of fish culture in stabilized sewage ponds, which were used as a source of water for growing vegetables, provided stimulus for the large-scale expansion of sewage-fed fish culture system. The area under this unique system of culture peaked at 12,000 ha, but in recent years there has been a steep decline in the area due to the increasing pressure from urbanization. Currently, the area under the sewage-fed culture system has been reduced to less than 4,000 ha and the poor people dependent on these wetlands for their livelihood have been severely affected. However, even today, a considerable amount of fish consumed in Kolkata city is produced from this system. There are appeals to the government to declare the existing sewage-fed aquaculture area as sanctuaries and to protect them from further encroachment by the rapidly expanding population of Kolkata city. In addition, 12,000 ha are also cultivated for growing vegetables.

Source: Extracted from Nandeesha (2002, p. 28).

The reuse of water in agriculture is one of the areas of great potential. It is already practised formally and informally in many countries (see Chapters 6 and 16). Reuse in peri-urban areas offers an opportunity to produce food close to the area of consumption.

5.5.1 Potable water reuse

The use of treated municipal wastewater for drinking is not quite so common, though well-established in some places (see Section 16.1.2). The populations of some countries, namely Australia, Namibia and Singapore, are already drinking treated wastewater, as are some populations in the USA, including in California, Virginia and New Mexico. It is usually safe, but public opinion is swayed by those who refer to 'toilet to tap' reuse as a way to discourage use.

Indirect potable reuse (IPR), whereby treated wastewater is added to ground or surface sources (where it receives additional treatment) and eventually ends up as drinking water, has become increasingly common (see Box 5.2). After tertiary treatment, the water is discharged to a storage reservoir for a period of six months or more. This level of treatment seems to assuage public fears about 'toilet to tap' concerns. In reality, a large proportion of treated and untreated wastewater ends up being discharged into a watercourse and used downstream as a water supply.

5.5.2 Non-potable reuse: Industrial, commercial, recreational and peri-urban agriculture

Local reuse becomes more economically feasible if the point of reuse is close to the point of production. Many industrial and commercial establishments are in need of process water, and can institute better housekeeping procedures to reduce their dependence on water consumption and wastewater production, as well as the associated costs. Businesses can directly reuse some untreated wastewater, provided it is of adequate quality. Good sources include process water for cooling or heating, and rainwater from industrial/commercial roof collection or airport aprons and runways.

Industrial symbiosis (see Chapter 6) is often used to describe partnerships and cooperation between two or more different industries to enhance both environmental performance and competitive capacity by exchanging and optimizing mutual material, energy and water flows. In the case of water reuse, this occurs often at a local scale. By-products of one industry become feedstocks in another. Similarly, process cooling water may be used for heat recovery or for productive use (Industrial Symbiosis Institute, 2008). Sometimes, partnerships share the management of utilities or ancillary services (see Box 6.4).

The United States Environmental Protection Agency (US EPA, 2004) gives a good account of urban reuse systems that provide partially treated (fit-for-purpose) wastewater for various non-potable purposes, including:

– irrigation of public parks and recreation centres, athletic fields, school yards and playing fields, highway medians and shoulders, and landscaped areas surrounding public buildings and facilities;

– irrigation of landscaped areas surrounding single-family and multi-family residences, general washdown, and other maintenance activities;

– irrigation of landscaped areas surrounding commercial, office and industrial developments;

– irrigation of golf courses;

– commercial uses, such as vehicle washing facilities, laundry facilities, window washing, and mixing water for pesticides, herbicides and liquid fertilizers; and

– ornamental landscape uses and decorative water features, such as fountains, reflecting pools and waterfalls.

In dual distribution systems, the partially treated wastewater is delivered to customers through a parallel network of distribution pipes separate from the community's potable water distribution system. The reclaimed water distribution system becomes a third water utility, in addition to wastewater and potable water. Reclaimed water systems are operated, maintained and managed in a way that is similar to the potable water system (US EPA, 2012). Direct use of treated municipal wastewater has been practised for some time, for example in St. Petersburg, Florida, where reclaimed water is provided for several residential properties, commercial developments and industrial parks, as well as a resource recovery power plant, a baseball stadium and some schools (US EPA, 2004).

Supplying nutritionally adequate and safe food to city dwellers poses a substantial challenge. Peri-urban agriculture offers one solution but requires adequate water. Municipal wastewater is often (usually informally) used without treatment, resulting in serious health risks for both farmers and those who consume the food. Social customs and diets dictate how risky this practice is. An example of direct wastewater reuse is the sewage-fed ponds in Kolkata, India (see Box 5.3).

5.6 Managing urban runoff

Climate change adaptation seeks to lower the flood risks associated with extreme rain events, but if developed in synergy with urban development, it can also address some of the problems associated with urban wastewater management. Cities are increasingly concerned with the effects of climate change, which include higher risks of flooding and raised temperatures, combined with increasing demands for safe drinking water supplies (State of Green, 2015).

Rainwater in the form of surface runoff can contribute to cities' water balance and be collected to create attractive recreational areas. A good example comes from Denmark (see Box 5.4), which shows how it is possible to use rainwater as a resource to create more resilient and liveable cities.

BOX 5.4 TREATING RAINWATER RUNOFF FROM INDUSTRIAL AREA, KOLDING, DENMARK

The local wastewater utility in the city of Kolding was facing the challenge of having to clean runoff from a highly polluted industrial area to protect the ecosystem of a small river nearby. The river was polluted with oil and hazardous substances derived from the industrial area where trucks were being loaded and a variety of materials were stored outside on the storage yard. To solve this problem, they applied the HydroSeparator® which is an automated and effective solution to improve water quality in various recipients while minimizing the need for retention basins at a much lower total cost of ownership. The maximum capacity of the HydroSeparator® was determined by the requirement of a maximum flow of 200 l/s discharges to the small river. It is built of two standard HydroSeparators of 100 l/s each, which can operate concurrently or separately. Today, the plant operates automatically with very low operating costs and can be monitored and controlled from the internet as well as the connected SRO-system from the wastewater utility Kolding Spildevand.

Source: Extracted from State of Green (2015, p. 18).

CHAPTER 6

UNIDO | UNIDO Industrial Resource Efficiency Division and John Payne, John G. Payne & Associates Ltd.

INDUSTRY

Wastewater treatment canal in a power plant

This chapter describes the extent and nature of industrial wastewater production. It also highlights the opportunities from the use and recycling of wastewater and the recovery of energy and useful by-products when addressing natural resource challenges in the context of sustainable industrial development.

The dawn of the industrial revolution in the eighteenth century in the now developed countries signalled the beginning of society's dilemma with the fate of industrial wastewater. Then and now, as is so often the case, it was discharged into natural watercourses in the mistaken belief that 'the solution to pollution is dilution' and that stormwater was Nature's purgative.

Societal and environmental pressures have, over time, led to a continuously growing movement that urged industry to reduce the amount of wastewater it produces, and to treat it before discharge. This has evolved into a significant paradigm shift, with wastewater now being seen as a potential resource, and its use or recycling after suitable treatment as a potential way to benefit industry economically and financially. This in turn complements the bigger picture of green industry, corporate social responsibility (CSR), water stewardship and sustainable development, including the SDGs and specifically Targets 6.3 and 6.a, which refer to wastewater (see Chapter 2).

These considerations apply mainly to large industries, some of which have a global reach into developing countries: many are moving from high-income countries to emerging markets (WWAP, n.d.). They have the size and resources to seize opportunities and enter the circular economy. Lacking this momentum, small- and medium-sized enterprises (SMEs) and informal industries often discharge their wastewater into municipal systems or directly into the environment, either of which creates another set of challenges and potentially lost opportunities (see Chapter 5).

6.1 Extent of industrial wastewater generation

As the volume of industrial wastewater is reported on a limited and sporadic basis, the real extent of this potential resource is largely unknown. Globally, data and information concerning the volume of wastewater produced by industry are very deficient. Moreover, a distinction needs to be made between the overall volume of wastewater produced and the volume that is actually discharged, which is generally lower due to recycling. One estimate suggests that the volumes of industrial wastewater will double by 2025 (UNEP FI, 2007).[5]

Some consolidated information is available from developed countries. In the EU, for example, limited data show that wastewater generation has generally decreased (Eurostat, n.d.). The data also show that manufacturing is the greatest generator of wastewater among the main industrial sectors (see Table 6.1). Furthermore, data from a few countries indicate that industry is a major polluter, as only a proportion of wastewater was treated before being discharged (see Table 6.2).

An atypical example of quite detailed country-level information (see Table 6.3) is available from Canada, which conducts biennial industrial water surveys that include data from manufacturing, mining and thermal-electric generating industries (see Box 6.1).

Statistics Canada (2014) reports that the paper industries produced almost 40% of the volume of manufacturing discharges, with nearly 80% having secondary or biological treatment, and accounted for 32% of the volume of recirculated water, with primary metals accounting for close to 50%. Overall, for manufacturing, the recirculation rate (recirculated water as a percentage of intake) was nearly 51%. For the water costs relating to manufacturing, about 38% went to effluent treatment and almost 10% to recirculation. Thermal-electric power was by far the largest user and discharger of water, of which almost 58% went untreated mainly to surface water bodies. Its recirculation rate was low though the volume was approximately double that of manufacturing. Mining was somewhat

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[5] Presumably referring to 2007 when the report was published.

Table 6.1 Generation of wastewater by type of industry, 2011 (million m^3)

	Industry total	Mining and quarrying	Manufacturing industries*	Production and distribution of electricity (excluding cooling water)**	Construction
Austria[1]	1 487.2	n.a.	889.6	363.3	n.a.
Belgium[2]	530.0	42.0	239.9	7.9	0.4
Bulgaria	153.6	12.5	91.3	37.9	0.6
Bosnia and Herzegovina	9.5	n.a.	9.5	n.a.	n.a.
Croatia	84.7	1.7	81.4	0.5	n.a.
Cyprus[5]	1.9	n.a.	1.9	0.0	n.a.
Finland	n.a.	n.a.	14.4	26.5	14.7
The Former Yugoslav Republic of Macedonia[2]	687.7	9.2	408.1	251.6	n.a.
Germany[1]	1 534.6	227.6	1 180.6	75.4	0.6
Hungary[4]	154.3	17.8	129.7	3.9	0.0
Latvia[3]	45.5	5.5	20.2	6.1	1.3
Lithuania	40.4	0.6	33.9	2.6	0.7
Poland	n.a.	342.9	484.6	79.8	6.6
Romania	n.a.	47.3	n.a.	n.a.	3.6
Slovenia	n.a.	0.1	42.8	n.a.	0.1
Slovakia	192.2	20.5	163.0	7.9	0.1
Spain[1]	6 335.2	47.2	602.0	n.a.	n.a.
Sweden[1]	878.0	26.0	839.0	14.0	n.a.
Serbia	76.8	10.3	36.3	30.2	n.a.
Turkey[1]	528.7	41.9	460.8	26.1	n.a.

n.a.: Not available

[1] 2010
[2] 2009
[3] 2007
[4] 2006
[5] 2005

Notes:
*Manufacturing industries include: food products; textiles; paper and paper products; refined petroleum products, chemicals and chemical products; basic metals; motor vehicles, trailers, semi-trailers and other transport equipment; other manufacturing.
**Production and distribution of electricity includes the activity of providing electric power, natural gas, steam, hot water and the like through a permanent infrastructure (network) of lines, mains and pipes.

Source: Eurostat (n.d., Table 7). © European Union, 1995–2016.

Table 6.2 Industrial wastewater discharges after treatment (as a % of total discharges), 2007–2011

	2007	2008	2009	2010	2011
Bosnia and Herzegovina	0.0	56.0	62.5	65.4	58.5
Bulgaria	59.7	57.1	49.6	50.8	46.8
Croatia	0.0	17.0	16.8	25.7	8.5
Czech Republic	47.7	44.3	45.7	52.4	60.2
The Former Yugoslav Republic of Macedonia	4.4	25.9	7.2	n.a.	n.a.
Germany	46.7	n.a.	n.a.	46.5	n.a.
Lithuania	0.0	73.5	72.5	60.4	51.8
Romania	0.0	12.7	9.7	14.1	5.6
Turkey	0.0	38.1	n.a.	71.9	n.a.

n.a.: Not available

Source: Eurostat (n.d., Fig. 5). © European Union, 1995–2016.

different with a recirculation rate over 100% (used mainly for processing) and discharge volumes greater than intake due to dewatering.

While many individual companies do collect and indeed report their wastewater data as required by regulations, with some exceptions, there are glaring gaps in all sectors collecting and collating data on national and global scales. These gaps will require bridging before water management policy can attempt to make good progress in coordinating water use and consumption with wastewater generation and discharges, the latter being often overlooked.

BOX 6.1 CANADIAN INDUSTRIAL WATER SURVEYS

Three sectors participate in the Canada Industrial Water Survey: manufacturing, mineral extraction, and fossil fuel and nuclear electric power-generating plants. Each sector has its own questionnaire that collects data on the volume of water brought into the facility, including information on the source, purpose, treatment and possible recirculation of this water, and also the volumes and levels of treatment prior to discharge. The questionnaires are developed in collaboration with data users in order to meet their statistical needs. Respondents were also consulted through individual meetings to ensure the information being asked was available and that the questionnaire could be filled out within a reasonable timeframe. Data are collected directly from survey respondents using mail-out/mail-back paper questionnaires. Mail-out occurs in the year following the reference year and is directed to an "environment manager or coordinator". Responding to the survey is mandatory and respondents are asked to return the completed questionnaires within 30 days of receipt. A letter explaining the purpose of the survey, the requested return date and the legal requirement to respond are included in the mail-out package and fax reminders are sent to respondents whose questionnaires are outstanding 45 days after the mail-out.

The questionnaires and reporting guides can be found here: www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvInstrumentList&Id=253674

Source: Adapted from Statistics Canada (n.d.).

6.2 Nature of industrial wastewater

Data regarding the general characteristics and quality of industrial wastewater are more available. The toxicity, mobility and loading of industrial pollutants have potentially more significant impacts on water resources, human health and the environment than actual volumes of water. This is reflected in Pollutant Release and Transfer Registries (PRTRs) (see Chapter 14), which contain

Table 6.3 Water intake, discharge and recirculation in Canadian industry, 2011 (million m^3)

	Total	Manufacturing	Thermal-electric power (including nuclear)	Mining
Total intake	27 600	3 677.5	23 497.2	429.2
% total volume	100	13.3	85.1	1.6
Total discharge[1]	26 900	3 226.8	23 082.6	587.9
% total volume	100	12.0	85.8	2.2
Treatment of discharge (%)				
Untreated		34.0	57.9	43.8
Primary		17.9	n.a.	47.6
Secondary		36.2	<<1	n.a.
Tertiary		12.0	n.a.	n.a.
Recirculation	6 000	1 870.0	3 711.2	465.1
% total volume	100	30.9	61.4	7.7
Recirculation rate[2] (as % of intake)		50.8	15.8	108.4
Use of recirculation (%)				
Process water		49.7		90.8
Cooling, condensing, steam		50.0	98.1	n.a.
Pollution control			0.1	
Other		0.3	1.7	n.a.

[1] The discharge volume is higher than the intake volume due to dewatering groundwater in some mines.

[2] Recirculation rate = Amount of recirculated water as a percentage of intake. The same water can leave a subsystem and re-enter it, or it is used in another subsystem many times, resulting in a recirculation rate higher than 100%.

n.a.: Not available

Source: Statistics Canada (2014).

information from developed countries on the amounts of selected polluting substances (above certain thresholds) released by industry into water, land and air (OECD, n.d.). Such databases could be analysed to obtain a general idea about the overall level of potential recoverable resources among the many undesirable contaminants.

Widely varying industrial activities produce wastewater, which is characterized by a broad spectrum of pollutants (see Table 6.4). Technology is available to remove (or 'mine') these pollutants and is only limited by its cost-effectiveness in given industrial situations. This creates two products: the treated water and the materials recovered. The water may be recycled within a plant or by another linked industry, or it may be simply discharged, returning it to the hydrological cycle for others to use. In the USA, it has been estimated that for some major rivers the water has been used and reused over 20 times before it reaches the sea (TSG, 2014). Useful materials may be recovered, such as minerals (phosphates) and metals (see Chapter 16). Cooling water may provide heat. Residual sludge might yield biogas or may have no other fate than disposal.

6.3 Addressing the resource challenge

If wastewater is accepted as a positive input, rather than an unwanted output, of industrial activity demanding disposal, there is a logical and preferred process from its elimination to pro-active use and recycling.

Table 6.4 Content of typical wastewater in some major industries

Industry	Typical content of effluent
Pulp and paper	• Chlorinated lignosulphonic acids, chlorinated resin acids, chlorinated phenols and chlorinated hydrocarbons – about 500 different chlorinated organic compounds identified • Coloured compounds and absorbable organic halogens (AOX) • Pollutants characterized by BOD, COD, suspended solids (SS), toxicity and colour
Iron and steel	• Cooling water containing ammonia and cyanide • Gasification products – benzene, naphthalene, anthracene, cyanide, ammonia, phenols, cresols and polycyclic aromatic hydrocarbons • Hydraulic oils, tallow and particulate solids • Acidic rinse water and waste acid (hydrochloric and sulphuric)
Mines and quarries	• Slurries of rock particles • Surfactants • Oils and hydraulic oils • Undesirable minerals, i.e. arsenic • Slimes with very fine particulates
Food industry	• High levels of BOD and SS concentrations • Variable BOD and pH depending on vegetable, fruit or meat and season • Vegetable processing – high particulates, some dissolved organics, surfactants • Meat – strong organics, antibiotics, growth hormones, pesticides and insecticides • Cooking – plant organic material, salt, flavourings, colouring material, acids, alkalis, oil and fat
Brewing	• BOD, COD, SS, nitrogen, phosphorus - variable by individual processes • pH variable due to acid and alkaline cleaning agents • High temperature
Dairy	• Dissolved sugars, proteins, fats and additive residues • BOD, COD, SS, nitrogen and phosphorus
Organic chemicals	• Pesticides, pharmaceuticals, paints and dyes, petro-chemicals, detergents, plastics, etc. • Feed-stock materials, by-products, product material in soluble or particulate form, washing and cleaning agents, solvents and added-value products such as plasticizers
Textiles	• BOD, COD, metals, suspended solids, urea, salt, sulphide, H_2O_2, NaOH • Disinfectants, biocides, insecticide residues, detergents, oils, knitting lubricants, spin finishes, spent solvents, anti-static compounds, stabilizers, surfactants, organic processing assistants, cationic materials, colour • High acidity or alkalinity • Heat, foam • Toxic materials, cleaning waste, size
Energy	• Production of fossil fuels – contamination from oil and gas wells and fracking • Hot cooling water

Sources: Based on IWA Publishing (n.d.); UNEP (2010); and Moussa (2008).

6.3.1 Reducing pollution and pollution prevention

As with many environmental issues, the first step is to prevent or minimize pollution. The goal is to keep the volumes and toxicity of pollution to a minimum at the point of origin. This goes to the core of new green industrial engineering, where the elimination of pollution and wastewater is part of the equation from concept to design for operations and maintenance. However, with established plants, while some re-engineering is possible, pollution reduction might be the only option. This includes substitution with more environmentally friendly raw materials and biodegradable process chemicals, as well as staff education and training to identify pollution issues and remedy them.

6.3.2 Removing contaminants

Industries discharging into municipal systems or surface water have to comply with discharge by-laws or other regulations to avoid fines, so in many cases end-of-pipe treatment is required at the plant before release. In some situations, industries find it also more economical to pay fines than to invest in treatment to meet regulations (WWAP, 2015).

Mixed effluents require complex treatment trains and result in one quality of wastewater discharge to meet local regulations. This water, because it must often meet stringent regulations, may be of unnecessarily higher quality than required for other fates, such as recycling applications. As it is usually more difficult and expensive to treat wastewater containing many pollutants than wastewater with only one such substance, stream separation is often desirable. Mixing more concentrated wastewater with streams that might be suitable for direct discharge or recycling should also be avoided (WWAP, 2006). However, in certain specific cases, appropriate blending of wastewater streams from different sources could potentially lead to beneficial effects in treatment. Either way, fit-for-purpose treatment can optimize the water quality for its next role.

There exists a myriad of possible treatment options, including stabilization ponds, anaerobic digestion and bioreactors to produce biogas, activated sludge, different types of membranes, UV radiation, ozonation, advanced oxidation and the use of wetlands of various sorts (see Table 4.2). In 2015, the oil and gas, food and beverage, and mining industries were expected to account for over half of all expenditures on wastewater treatment technologies, and further growth in technology was anticipated for meeting strict discharge requirements, for example in the mining sector (see Box 6.2). By 2020, the market for industrial water treatment technologies is predicted to grow by 50% (GWI, 2015).

6.3.3 Recycling wastewater and recovering by-products

Recycling within a plant. Overall, industry is in a good position to use or recycle its wastewater internally. This might involve the direct use of untreated wastewater, provided its quality is good enough for the intended purpose. Cooling and heating water, as well as rainwater, may be suitable for washing, pH adjustment and fire protection. However, process water which is sufficiently treated to match resulting quality with intended purpose has more potential for recycling, for example in conveying materials, rinse water, water-cooling towers, boiler feed, production line needs, dust suppression, and washing (see Box 6.3). This quality is accomplished by decentralized treatment systems. While the technology is generally available, as noted in Box 6.2, and there is a trend to reduce the gap between treatment and recycling

> By 2020, the market for industrial water treatment technologies is predicted to grow by 50%

BOX 6.2 ANGLO AMERICAN EMALAHLENI WATER RECLAMATION PROJECT, MPUMALANGA, SOUTH AFRICA

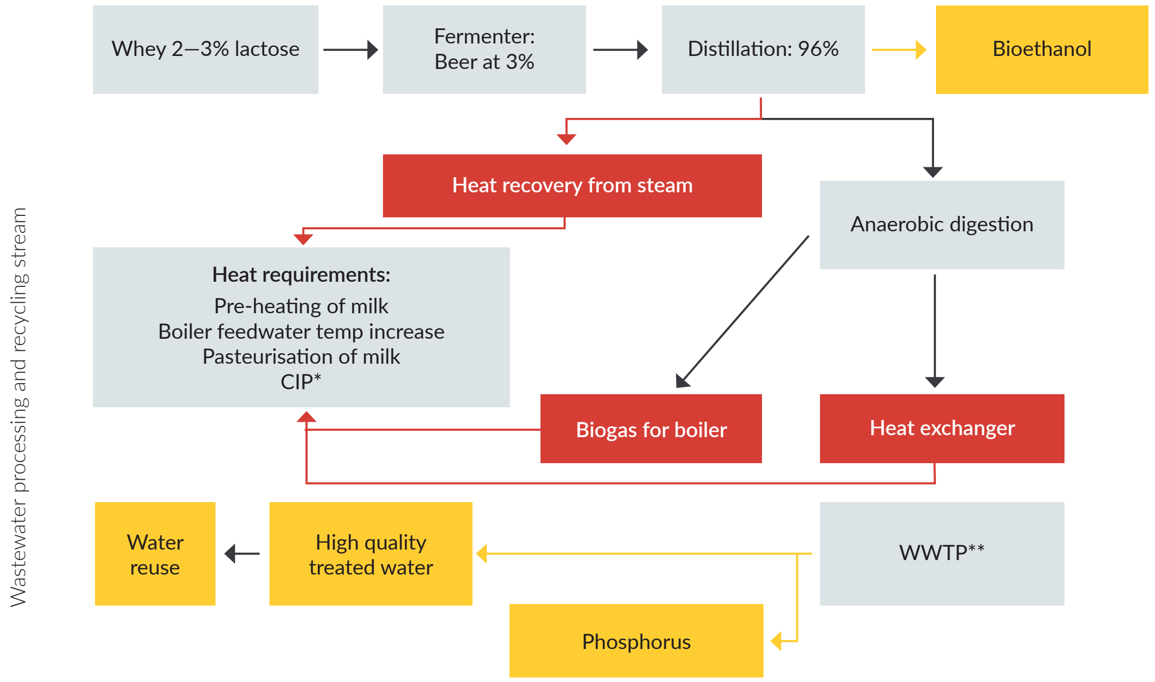
The Witbank coalfields are located around eMalahleni, a city of half a million inhabitants in north-eastern South Africa. The region struggles with water scarcity that is expected to become more severe in the future, while eMalahleni already has difficulty in meeting the water demands of its rapidly expanding population. The water reclamation initiative was started to ensure environmentally responsible management of excess water in the mines, and a continuous supply of treated water for mining activities, while eliminating the need to import water and the consequent competition with other stakeholders for a scarce resource.

The eMalahleni Water Reclamation Plant treats water from the three Anglo American thermal coal operations and uses desalination technology. Water from the mine is converted to drinking water, process/industrial water and water that can be safely released into the environment. In the treatment process, gypsum is separated from the water and used as a construction material.

Some of this treated water is used directly in mining operations, but the majority is for social use and meets 12% of eMalahleni's daily water needs offering a reliable and potable water supply. Anglo American is minimizing its water footprint and environmental impact while delivering long-term benefits of safe and uninterrupted access to coal reserves from operating mines, and eliminating both the need to import water and the uncontrolled release of water from participating mines.

Source: Adapted from WBCSD/IWA (n.d.).

BOX 6.3 CREATIVE USE OF WASTEWATER AT CARBERY MILK PRODUCTS IN CORK, IRELAND



* CIP: Clean-in-place
**WWTP: Wastewater treatment plant

The dairy industry in the US produces large amounts of wastewater: for every litre of milk, it uses 1.5–3 litres of water. Typically, the wastewater has approximately 10 times the organic loading of municipal wastewater. Whey is a by-product of cheese-making and commonly used for feeding pigs or making other products. However, there is a large surplus which is very energy-intensive to treat as wastewater. The main ingredient of whey is lactose and this can be fermented into ethanol in a creative process of wastewater recycling. Carbery Milk Products in Cork, Ireland, was the first dairy producer in the world to do this.

The whey is put through microfiltration and reverse osmosis and the lactose goes to a fermenter where it is turned into beer before going on to a distillation system to produce a 96% ethanol product for the bioethanol fuel market. All the bioethanol in Ireland comes from this one plant and it is the only European country not using sugarcane-based ethanol from Brazil.

The steam from the distillation process is recovered and used to pre-heat boiler water, heat water for clean-in-place (CIP) and for pasteurization, thus saving energy.

The waste stream from the fermentation is sent to an anaerobic digester and produces biogas which is used to produce additional heating.

The warm wastewater from the anaerobic digester is passed through a heat exchanger to pre-heat the incoming chilled milk. Thus, the wastewater is cooled to a suitable temperature for discharge into the local river without affecting the environment.

At the same time, the wastewater has a large concentration of phosphorus of which 99% must be removed before discharge. The phosphorus is recycled back to agricultural land.

The company wants to expand the plant and the resulting high-quality treated effluent is potentially suitable for recycling at the site, particularly as boiler feedwater, as the amount of water that the plant can withdraw from the local river is limited. Moreover, recycling would reduce discharges to the river, particularly during seasonal low flow, when the dilution capacity is lower. Polishing the already high-quality effluent using advanced oxidation is being investigated, as it is cheaper than buying potable water. The water would go into the reverse osmosis plant, which demineralizes the water. This has the added benefit of reducing membrane fouling and reducing cross-contamination as it has no direct contact with food products.

Source: Adapted from Blue Tech Research (n.d.).

BOX 6.4 KALUNDBORG SYMBIOSIS IN KALUNDBORG, DENMARK

The Kalundborg Industrial Symbiosis is an "industrial ecosystem" where the by-products of one enterprise are used as a resource by other enterprises, in a closed cycle. It began in 1961 with the development of a new project to use surface water from Lake Tissø for a new oil refinery with the aim of saving the limited supplies of groundwater. The City of Kalundborg was in charge of building the pipeline while the refinery was responsible for the financing.

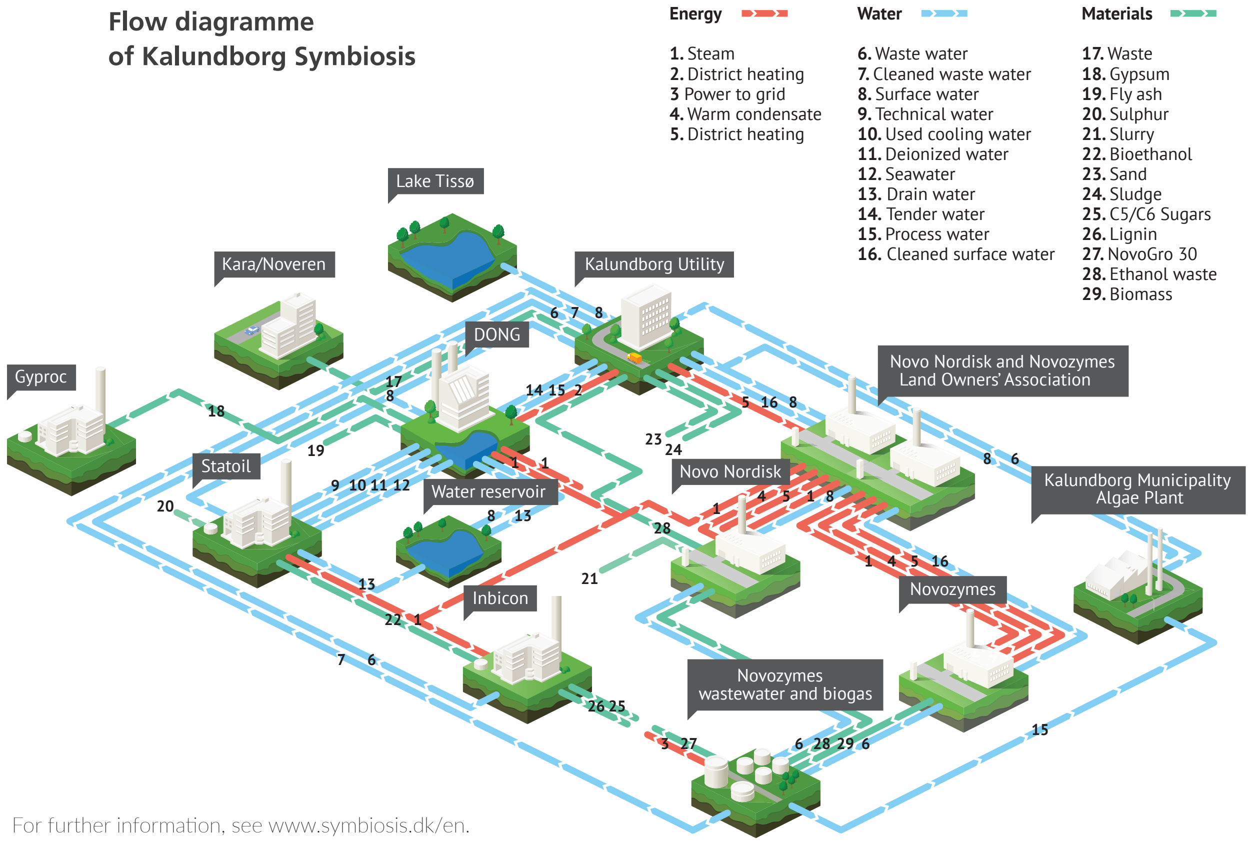
The Kalundborg Industrial Symbiosis has developed gradually over several decades from initiatives and individual cooperation between companies of different sectors driven by economic advantages, with support from the Kalundborg Municipality. Nowadays, it is a project mainly financed by the symbiosis partners.

The symbiosis involves exchange of all sorts of materials, including wastewater, as shown in the flow diagram below.

Water Cascading Initiatives: The Asnæs Power Station receives 700,000 m^3 of cooling water from Statoil each year, which it treats to use as boiler feed water. It also uses about 200,000 m^3 of Statoil's treated wastewater for cleaning each year. The cooling water becomes steam that is provided back to Statoil, as well as to other business, such as a local fish farm. The savings to local water resources are considerable – nearly 3 million m^3 of groundwater and 1 million m^3 of surface water per year (Domenech and Davis, 2011).

The power plant uses salt water from the fjord for some of its cooling needs. As a result, it reduces the withdrawals of freshwater from Lake Tissø. The resulting by-product is hot salt water, an amount of which goes to the fish farm's 57 ponds.

Heat Cascading Initiatives: Asnæs started supplying the city with steam for its new district heating system in 1981. Then, Novo Nordisk and Statoil joined in as customers for steam. This system of district heating was encouraged by the city and the Danish government and thus replaced about 3,500 oil furnaces.



For further information, see www.symbiosis.dk/en.

Source of illustration: Kalundborg Symbiosis (n.d.).

Sources: Adapted from EC (2016, Box 9, p. 25) and Industrial Ecology (n.d.).

(GE Reports, 2015), obstacles may include implementation, costs not outweighing benefits, long payback periods, maintenance and increased energy consumption. Moreover, the location and availability (intermittent, batch or continuous production) of the wastewater stream must fit with its intended use.

Using wastewater or recycling treated wastewater is a process that can be repeated many times. It not only reduces the cost for industry of acquiring freshwater by decreasing intake, particularly in areas or times of scarcity, but also has the added benefit of reducing discharges. In this way, the need to meet regulatory standards and the risk of fines is minimized. Furthermore, the practice benefits the environment and adds weight to any social license to operate.

Industrial symbiosis. One notable opportunity for industrial wastewater use and recycling is the cooperation between plants in industrial symbiosis (SSWM, n.d.). This can involve the exchange of process water or the recycling of treated wastewater for purposes similar to in-plant recycling. Examples include steam or hot wastewater, or wastewater that contains organic material and nutrients, and unconverted raw materials that may be economic to recover: oil, used solvents, starch and other substances that can be traded or recycled, perhaps by employing waste registers between adjacent industries (WWAP, 2006). The treatment technology options are similar to those for in-plant purposes and may employ decentralized systems. These may involve a dedicated centralized wastewater treatment plant that services all the industries.

Eco-industrial parks. Industrial symbiosis is best seen in eco-industrial parks which strategically locate industries adjacent to one another to take convenient advantage of wastewater management and recycling (see Box 6.4). For SMEs, this can be a significant way to save on wastewater treatment costs. Important factors are the sharing of information to match needs, reasonable proximity, and reliability of supply in terms of quantity and quality. Combined Heat and Power Plants (CHP, or cogeneration), which require substantially less cooling water than conventional generation, are more efficient when they are located near to the demand for heat and power such as an industrial complex and as decentralized power supply (Rodríguez et al., 2013). Interesting examples of eco-industrial parks are found in many countries, for example the Shanghai Chemical Industrial Park in China (WWAP, 2015).

The Kalundborg Industrial Symbiosis is an "industrial ecosystem" where the by-products of one enterprise are used as a resource by other enterprises, in a closed cycle. It began in 1961 with the development of a new project to use surface water from Lake Tissø for a new oil refinery with the aim of saving the limited supplies of groundwater. The City of Kalundborg was in charge of building the pipeline while the refinery was responsible for the financing.

BOX 6.5 INDUSTRIAL AND ENERGY USE OF MUNICIPAL WASTEWATER

The Tarragona site of a water reclamation unit in the south of Catalonia, Spain, utilizes secondary effluent from two municipal wastewater plants, treating it for industrial users. The Tarragona area is highly water-stressed and water unavailability hinders further growth in the region. Water recycling in an industrial park (a petrochemical complex) will free up existing raw water rights to meet future local (municipal and tourism) demand. The final target is to meet 90% of the water demand of the industrial park from recycled water (DEMOWARE, n.d.).

Terneuzen is situated in the southwest of the Netherlands. The industrial site of Dow Terneuzen originally planned to use desalinated seawater as a source, but the increasing cost of this proved to be problematic due to quality problems, corrosion, etc. As a result, the nearby municipal wastewater treatment plant was re-engineered to provide reclaimed water to the industrial complex (10,000 m^3 per day). The water is used to generate steam and feed its manufacturing plants. After the steam is used in the production processes, the water is again used in cooling towers until it finally evaporates into the atmosphere (so it is 'recycled' a second time). Compared with the energy cost needed for conventional desalination of seawater for the same use, Dow Terneuzen has reduced its energy use by 95% by reclaiming urban wastewater – the equivalent of reducing its carbon dioxide emissions by 60,000 tonnes each year. Dow is now using this experience gained in Europe at its site in Freeport, Texas, USA (World Water, 2013).

The LIFE WIRE project is a LIFE12 project being implemented in Barcelona, Spain, that aims to boost industrial recycling of treated wastewater by demonstrating the feasibility of water recycling through the use of satellite treatments able to produce fit-for-use water quality. The project studies the feasibility of technology configurations based on the combination of ultrafiltration, carbon nanostructured material filtration and reverse osmosis to use treated urban wastewater in industries. The project technically and economically assesses the benefits of using the proposed treatment scheme over the current conventional treatments in three industrial sectors: electrocoating, chemical and liquid-waste disposal.

Sources: Extracted from EC (2016, Box 8, p. 25).

> Industry needs to ‘produce more with less’, which in the case of water means running drier

The upside of eco-industrial park wastewater arrangements is similar to those for in-house recycling (SSWM, n.d.). The downside include the need for long-term commitments to justify the initial capital expenditures, and the need for further treatment to meet some industries’ needs and possibly regulatory approval hurdles.

Multiple-use systems (MUS) involving cascading reuses of water from higher to lower quality within a river basin may have industrial components, for example, where domestic wastewater may be reclaimed for washing and cooling (UNEP, 2015c).

Reclaiming urban wastewater. Industry can assist on the other side of the wastewater equation by using reclaimed urban wastewater from municipalities (see Box 6.5): this inter-sector water reuse is growing quickly in many countries (WBCSD, n.d.). It is a very pro-active measure of sustainability as it reduces the requirements for freshwater intake, which is particularly important in areas of water scarcity, and reduces overall municipal discharges. Issues of timing of wastewater availability and its transport to the target industrial plants also need to be worked out. In some cases, municipalities will custom-treat wastewater for specific industries which may not need perfectly clean drinkable water. In California, for example, the Central and West Basin Municipal Water Districts offer reclaimed water of different qualities and costs, including process water for petroleum refining. The State Water Resources Control Board also promotes wastewater for power plant cooling (California Department of Water Resources, 2013).

6.4 Wastewater and sustainable industrial development

Water is not only an operational challenge and a cost item in industry, it is also an opportunity for growth as the incentives for minimizing water use (which includes wastewater use and recycling) reduce costs and water dependency (WBCSD, n.d.). Industry needs to ‘produce more with less’, which in the case of water means running drier (UNIDO, 2010).

As the reduction of freshwater intake is linked to a decrease in wastewater discharges, there is a major role to be played by cleaner production initiatives that focus on reducing overall water use, closing the water cycle, eliminating wastewater discharge (zero discharge), and reducing or eliminating solvents and toxic chemicals (UNEP, 2010). Cleaner production through green industry creates value by lowering operational costs through the elimination of inefficiencies by using the 3R strategy (reduce, recycle, reuse), which also helps limit environmental impacts (UNIDO, 2010). For example, the UNIDO Transfer of Environmentally Sound Technology (TEST) programme has targeted wastewater pollution from industry on the Danube River, with the goal of improved water efficiency and less wastewater discharges, by analysing the issues and problems and introducing cleaner production solutions and new technology (UNIDO, 2011). Resource efficiency and enhanced environmental performance have even been shown to generate economic benefits for certain SMEs (see Box 14.3).

More broadly speaking, cleaner production has an important place in industrial ecology, which also includes pollution control, eco-efficiency, life-cycle thinking and closed loop production. These allow the identification of opportunities for enhanced resource efficiency and value-adding activities. The ultimate goal is zero discharge – the situation in which all water is recycled within a plant or traded to another, and the only consumption is through evaporation, which in theory means all the wastewater is used or recycled and there is no discharge (except for minor losses). At that point, water withdrawal (intake) equals consumption (WWAP, 2006). However, the Jevons Paradox[6] can take effect: as water efficiency improves, overall water use may in fact increase, with lower cost of production and corresponding increased industrial output.

Once an industry knows its water footprint and pedigree, it can target its wastewater generation to look for possibilities of water reuse and recycling. Moreover, it can expand its efforts into water neutrality (Hoekstra, 2008), which means that after the industry has made efforts to use or recycle its wastewater, the negative impacts of remaining water pollution can be compensated for by investing in projects that promote the sustainable management of water (i.e. wastewater treatment) within local environments. Thus, wastewater might also be seen as resource for promoting investment.

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[6] In the nineteenth century, William Stanley Jevons argued that gains in technological efficiency did not decrease the use of coal and other resources, but actually increased their consumption and production (Alcott, 2005).

CHAPTER 7

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AGRICULTURE

Irrigation system in Thailand

This chapter reviews the main pollutants from agriculture, its associated impacts, and offers some key pollution mitigation options. The chapter also discusses how agriculture can be a beneficial user of wastewater, and how the practice can become safe.

Agriculture is both a producer and user of wastewater. As a result, the sector can both cause and suffer the consequences from pollution.

The intensification of agriculture has increased in recent years, both in industrial and traditional farming, contributing not only to the increase in agricultural productivity, but also resulting in higher waterborne pollution loads, which affects ecosystems and human health. At the same time, industries and cities are expanding and contributing to higher loads of pollution entering the water used in agriculture, with adverse effects for the sector.

7.1 Agriculture[7] as a source of water pollution

Over the past half century, agriculture has expanded and intensified in order to meet the increasing food demand triggered mainly by population growth and changes in diet. The area equipped for irrigation has more than doubled, from circa 1.4 million km^2 in 1961 to circa 3.2 million km^2 in 2012 (AQUASTAT, 2014). Total livestock has more than tripled from 7.3 billion units in 1970 to 24.2 billion in 2011 (FAOSTAT, n.d.a.). Aquaculture, especially inland fed aquaculture and particularly in Asia, has grown more than twentyfold since the 1980s (FAO, 2012).

Agriculture intensification has frequently come with increased soil erosion, higher sediment loads in water, and excessive use (or misuse) of agricultural inputs (e.g. pesticides and fertilizers) to increase productivity. When the use of such products exceeds the assimilation capacity of agricultural systems, it results in higher pollution loads to the environment. The excess use of irrigation water also enhances the agricultural wastewater flows back into water bodies in the form of deep percolation to aquifers and runoff to surface waters.

7.1.1 Agricultural pollutants: sources and impacts

Agricultural activities release several types of pollutants into the environment (see Table 7.1). These pollutants impact aquatic ecosystems as a result of export from farms, transportation along the hydrological cycle and concentration in water bodies. Typical pollution pathways are: i) percolation to groundwater; ii) surface runoff, drainage water, and flows to streams, rivers and estuaries; and iii) adsorption onto sediments from natural or human-induced soil erosion to sediment-rich streams (FAO/CGIAR WLE, forthcoming).

NUTRIENTS

Natural nutrient sources (and nutrient recycling) have been supplemented with fertilizers to increase agricultural production since the nineteenth century. The excessive mobilization of nutrients is now claimed to have gone beyond the planetary boundaries (Rockström et al., 2009).

In crop production, water pollution from nutrients occurs when fertilizers are applied more heavily than crops can absorb them, or when they are washed off the soil surface before they can be incorporated into plants. Excess nitrogen and phosphates can leach into groundwater, or as surface runoff into waterways. While nitrates and ammonia are very soluble, phosphate is not, and it tends to get adsorbed to soil particles. It enters water bodies attached to sediments through soil erosion.

In livestock production, feedlots are often located on the banks of watercourses so that (nutrient-rich) animal waste (i.e. urine) can be released directly into the watercourse. Solid waste (manure) is usually collected to be used as organic fertilizer. In many cases, however, it is not stored in contained areas and washes off by surface runoff into watercourses when there is significant rainfall. In wastewater-fed aquaculture, nutrient loads to water are primarily a function of feed composition and feed conversion (faecal waste). Wastage of

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[7] Agriculture in this chapter refers to plant and crop production, aquaculture and livestock activities.

Table 7.1 Categories of major water pollutants from agriculture and the relative contribution from agricultural production systems

Pollutant category	Indicators / Examples	Relative contribution from		
		Crop production	Livestock	Aquaculture
Nutrients	Primarily nitrogen and phosphorus that are present in chemical and organic fertilizer, animal excreta, and present in water as nitrate, ammonia or phosphate	***	***	*
Pesticides	Herbicides, insecticides, fungicides and bactericides, including organophosphates, carbamates, pyrethroids, organochlorine pesticides and others (many, like DDT, are banned in most countries but their illegal use persists)	***	–	–
Salts	Including sodium (Na^+), chloride (Cl^-), potassium (K^+), magnesium (Mg^{2+}), sulphate (SO_4^{2-}), calcium (Ca^{2+}) and bicarbonate (HCO_3^-) ions, among others*	***	*	*
Sediment	Measured in water as total suspended solids or nephelometric turbidity units – especially from pond drainage during harvesting	***	***	*
Organic matter	Chemical or biochemical substances that require dissolved oxygen in the water for degrading (organic materials, such as plant matter and livestock excreta)**	*	***	**
Pathogens	Bacteria and pathogen indicators, including *E.coli*, total coliforms, faecal coliforms and *Enterococci*	*	***	*
Metals	Including selenium, lead, copper, mercury, arsenic, manganese and others	*	*	*
Emerging pollutants	Drug residues, hormones, feed additives, etc.	–	***	**

*Measured in the water, directly as total dissolved solids, or indirectly as electric conductivity
**Measured in the water as COD and BOD

Source: FAO/CGIAR WLE (forthcoming).

feed (feed not taken up by the fish) in intensive fed-aquaculture can significantly contribute to nutrient loads in the water.

These nutrient loads can lead to the eutrophication of lakes, reservoirs and ponds, causing an algae bloom which suppresses other aquatic plants and animals (FAO, 2002). Excessive accumulation of nutrients may also increase adverse health impacts such as the blue baby syndrome, which can be caused by high nitrate levels in drinking water (WHO, 2006a).

PESTICIDES

In many countries, insecticides, herbicides and fungicides are heavily applied in agriculture (Schreinemachers and Tipraqsa, 2012). When improperly selected and managed, they can pollute water resources with carcinogens and other toxic substances that can affect humans and many forms of wildlife. Pesticides may also affect biodiversity by destroying weeds and insects, which can have negative impacts further up in the food chain. In the developed world, even though the use of older broad-spectrum pesticides is still widespread, the trend is toward newer pesticides that are more selective and less toxic to humans and the environment, and that require a lower application per hectare to be effective.

Currently, millions of tonnes of active pesticide ingredients are used in agriculture (FAOSTAT, n.d.b) and cases of acute pesticide poisoning account for significant morbidity and mortality worldwide, especially in developing countries (WHO, 2008), where poor farmers often use severely hazardous pesticide formulations rather than safer alternatives.

SALTS

Over the last decades, the production of brackish drainage and leaching water from agriculture has grown proportionally to the increase in irrigation.

Salts accumulated in soils can be mobilized by irrigation (leaching fractions), transported by drainage water, and cause salinization of receiving water bodies. In addition, excessive irrigation can raise water tables from saline aquifers and this can increase seepage of saline groundwater into water courses and increase their salinization. Intrusion of saline seawater into aquifers is another important cause of salinization of water resources in coastal areas. This intrusion is frequently the result of excessive groundwater extractions for agriculture (Mateo-Sagasta and Burke, 2010).

Major water salinity problems have been reported in the USA, Australia, China, India, Argentina, Sudan and many countries in Central Asia (FAO, 2011). In 2009, approximately 1.1 billion people lived in regions that had saline groundwater at shallow and intermediate depths (van Weert et al., 2009).

Highly saline waters alter geochemical cycles of other major elements, e.g. carbon, nitrogen, phosphorus, sulphur, silica and iron (Herbert et al., 2015), with overall impacts on ecosystems. Salinization can affect freshwater biota at three levels: i) changes within species; ii) changes in the community composition, and; iii) eventually biodiversity loss and migration. In general, when salinity concentrations rise, a decline in biodiversity is observed (including microorganisms, algae, plants and animals) (Lorenz, 2014).

SEDIMENTS AND OTHER POLLUTANTS

Unsustainable land use and improper tillage and soil management in agriculture are major causes of erosion and sediment runoff into rivers, lakes and reservoirs. Sediment in river systems is a complex mixture of mineral and organic matter, which can cause reservoir siltation and affect aquatic life by altering and suffocating habitats, and clogging fish gills. Sediments can also be a carrier of chemical pollutants, such as pesticides or phosphate.

Agriculture can also be a source of several other types of pollutants, including organic matter, pathogens, metals and emerging pollutants. Excess of organic matter depletes oxygen from the water bodies and increases the risk of eutrophication and algal blooms in lakes and reservoirs. Over the last 20 years, new agricultural pollutants have emerged, such as antibiotics, vaccines, growth promoters and hormones that may leach from livestock and aquaculture farms into the water, leading to increasing risks for ecosystems and human health. Residues of heavy metals in agricultural inputs such as fertilizers or animal feed are also emerging threats.

7.1.2 Responses to agricultural pollution

KNOWLEDGE AND RESEARCH

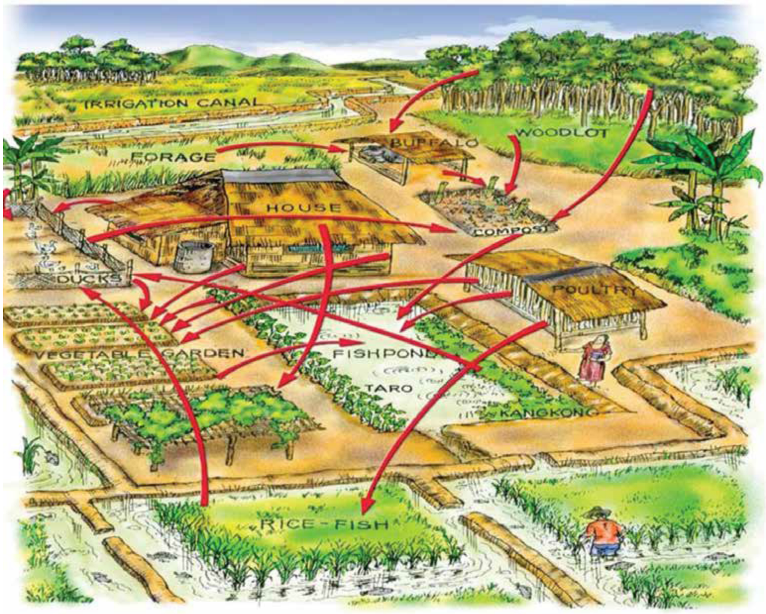
The knowledge gaps related to water pollution from agriculture are considerable. The actual contribution of crops, livestock and aquaculture to water pollution is not known for most basins and countries, particularly in the developing world. Such knowledge is essential for national governments to understand the extent of the problem and to develop meaningful and cost-effective policies. Moreover, if the pollution source is not well known, the polluter pays principle cannot be applied. A sustained research and modelling effort, supported by water quality monitoring, would be needed to better understand the pollutant pathways. Robust assessments to understand the pathways, as well as the health and environmental risks from emerging agricultural pollutants, such as animal hormones, antimicrobial and other pharmaceuticals, are also needed.

POLICIES AND INSTITUTIONS

An adequate policy framework is needed to enable the effective control of water pollution from agriculture. Policies can be implemented through several types of instruments: laws and regulations, plans and programmes, economic instruments and information, and awareness and education programmes (FAO, 2013b). Such instruments need to provide farmers with the right incentives for the adoption of good agricultural practices for pollution control.

As environmental and food production policies are normally developed by different ministries, the sense of shared responsibility for pollution legislation and control is generally lacking. There are many cases where this has led to conflict between policies aimed at increasing food production and farm income on the one hand, and on mitigating inland and coastal pollution on the other. Enhanced inter-ministerial cooperation mechanisms are required to develop more coherent policies. Plans and programmes on water pollution control need to be adopted at the basin or watershed scale and cover different sources of pollution – including industry and urban areas, in addition to agriculture – and ideally identify those cases in which wastewater from one sector can become a resource for another sector, in a circular economy.

Figure 7.1 Integrated agriculture-aquaculture



Source: FAO (2013b, Fig. 7.3, p. 93).

ON-FARM PRACTICES

On-farm practices play a crucial role in managing and mitigating agricultural pollution. In crop production, management measures to reduce the risk of water pollution by organic and inorganic fertilizers and pesticides include: i) the limitation and optimization of the types, amounts and timing of application of fertilizers and pesticides to crops; ii) the establishment of buffer strips along surface watercourses; and iii) the establishment of protection zones around groundwater supply sources. Moreover, efficient irrigation schemes can greatly reduce both water and fertilizer loss (Mateo-Sagasta and Burke, 2010). For erosion control, good management (i.e. contour ploughing) or restrictions on the cultivation of steeply sloping soils are needed (US EPA, 2003).

The problem of water quality in the livestock and aquaculture sector arises from solid and liquid waste (FAO, 2013b). Manure produced in livestock, for instance, is a valuable material for improving soil fertility and can save on fertilizer costs. However, it is highly polluting if spread at the wrong time or in the wrong place. Without sufficient precautions, livestock and aquaculture practices can also contribute to the microbiological contamination of rivers and groundwater. Therefore, measures to control and eliminate the spreading of pathogens (i.e. bacteria from livestock slurries) and other pollutants (i.e. nitrate) are critical.

The risks associated with brackish or saline agricultural drainage (return flow) also need to be managed. Relevant water management options include the minimization of drainage by conserving water, treatment of drainage water (i.e. evaporation ponds for saline drainage), or water reuse. Brackish or saline drainage water can be reused directly downstream, or blended with freshwater. These approaches would require planning at the watershed level to adapt agriculture practices and crops to the increasing salt content after different cycles of reuse, which can also include the production of prawns and fish in brackish or saline waters.

Integrated aquaculture-agriculture (see Figure 7.1), where crops, vegetables, livestock, trees and fish are managed collectively, can lead to increases in the stability in production, resource-use efficiency and environmental sustainability. Integrated farming ensures that waste from one enterprise become an input in another farm. In this way, the use of resources is optimized and pollution is reduced (FAO, 2013b).

7.2 Agriculture as a user of wastewater

With increasing demands for agricultural commodities, farmers are looking into non-conventional water sources. Due to its high nutrient content, domestic and municipal wastewater presents an attractive option, especially where conventional water resources are scarce or lacking.

If wastewater is used in agriculture without the necessary safety precautions, microbiological and chemical pollutants can accumulate in crops, livestock products, soil or water resources, and lead to severe health impacts for exposed food consumers and farm workers. However, if adequately treated and safely applied, wastewater is a valuable source of both water and nutrients, contributing to food security and the improvement of livelihoods.

Wastewater may be used directly or indirectly in agriculture. *Direct* use refers to planned and deliberate use of treated or untreated wastewater for some beneficial purpose, including irrigation, aquaculture and livestock. *Indirect* use occurs when treated, partially treated or untreated wastewater is discharged into reservoirs, rivers and other water bodies, including groundwater, that supply water for agriculture. Indirect use poses the same health risks as planned wastewater use projects, but may have a greater potential for health problems because the water user is unaware of the wastewater being present (FAO, 1997).

Another important way in which wastewater is used indirectly for agriculture is by means of managed aquifer recharge (MAR) in which treated or partially treated wastewater is infiltrated into aquifers through ponds, trenches, lagoons or injection wells and subsequently re-abstracted (Dillon et al., 2012). In many cases, the soil and the unsaturated zone of the aquifer help to remove pollutants from the wastewater so that the re-abstracted groundwater can be used for all types of crops.

> If adequately treated and safely applied, wastewater is a valuable source of both water and nutrients, contributing to food security and the improvement of livelihoods

Wastewater is typically rich in both suspended solids (particulates) and dissolved nutrients. To optimize water reuse, its quality, quantity and location are important factors to be considered (Iannelli et al., 2011).

7.2.1 Wastewater use: an opportunity for agriculture

IRRIGATION

According to FAO's AQUASTAT (n.d.b.), around 3,928 km³ of water per year is withdrawn worldwide (see Figure 1, Prologue), of which 44% (1,716 km³ per year) is consumed and 56% (2,212 km³ per year) is released as wastewater, including agricultural drainage and wastewater.

Municipal wastewater accounts for the majority of wastewater directly used in agriculture. Municipal water demand corresponds to 11% of global water withdrawal (AQUASTAT, n.d.b.). Out of this, only 3% is consumed and the remaining 8% is discharged as wastewater, representing 330 km³ per year (Mateo-Sagasta et al., 2015), much of which could potentially be used for agricultural irrigation.

Agricultural drainage and wastewater, on the other hand, account for 32% (1,257 km³ per year) of water withdrawal. This highlights the fact that policies, planning and implementation should not be entirely focused on municipal wastewater management, but also on sustainable agricultural drainage, return flow and wastewater management. As discussed above, water reuse for agriculture can have significant health benefits, including increased food security and improved nutrition.

Today, the planned use of municipal wastewater is a common pattern in countries of the Middle East and North Africa (MENA), Australia, and the Mediterranean, as well as in Mexico, China and the USA (AQUASTAT, n.d.b.). However, there is no comprehensive inventory of the extent of treated or untreated wastewater used in agriculture, apart from the incipient efforts by institutions like AQUASTAT (n.d.a.). Inadequate wastewater treatment and the resulting large-scale water pollution suggest that the area irrigated with unsafe wastewater is probably ten times larger

> **Currently, millions of tonnes of active pesticide ingredients are used in agriculture and cases of acute pesticide poisoning account for significant morbidity and mortality worldwide, especially in developing countries**

than the area using treated wastewater (Drechsel and Evans, 2010).

According to FAO, globally 2.75 million km^2 of land are actually irrigated (AQUASTAT, 2014). The approximately 330 km^3 of municipal wastewater generated every year could potentially irrigate 40 million hectares (with approx. 8,000 m^3 per hectare) (Mateo-Sagasta et al., 2015), or 15% of all irrigated lands. Estimates of the total area that is being irrigated with raw and diluted wastewater are still fragmentary, but the numbers are likely to range between 5 and 20 million hectares, with the largest share probably in China (Drechsel and Evans, 2010), which translates to between 2% and 7% of the world's total irrigated area.

The low percentage of wastewater that is being used by agriculture in a planned manner – and its unsafe application in most cases – confirms the vast potential for improving and increasing the application of used water (from municipal, industrial and agricultural sources) to meet the water demand for global food production.

AQUACULTURE AND LIVESTOCK

The objective of fertilizing an aquaculture pond with excreta or wastewater is to produce natural food for fish (see Box 5.4). A wide range of fish species have been cultivated in this manner. Fish can be grown in ponds that receive effluent or sludge, where they can feed on algae and other organisms that grow in the nutrient-rich water. The fish, thereby, remove the nutrients from the wastewater and are eventually harvested for human consumption or as feed.

The quality and condition of the fish will influence local acceptance. The microbial flora of a fish reflects that of the water from which it was taken (e.g. in the digestive tract, on the skin or in the fluids of the body cavities). There may be concern about contamination of the fish, especially when they are harvested, cleaned and prepared. If they are cooked well, they should be safe, but it is advisable to move the fish to a clear-water pond for several weeks before they are harvested for human consumption.

The use of water by livestock, and the contribution of livestock to water supply depletion, is high and growing (FAO, 2006). Animal products have a particularly large water requirement per unit of nutritional energy produced compared to food of plant origin (Gerbens-Leenes et al., 2013). Safe use of wastewater may have a significant role in replacing freshwater for producing harvested fodder (e.g. hay or silage), or for service water replacement (e.g. cooling and cleaning facilities). The usage of wastewater in the livestock sector, whether from municipal/industrial production or from the same livestock facility, is primarily dictated by the quality of the wastewater. A minimum of secondary treatment and disinfection is generally recommended. In addition, reclaimed water intended for use with cattle must have been treated to remove helminth parasites. Such treatment can either be based on lagooning (for a period of 25 days or longer) or on an approved method of filtration, such as sand or membrane filtration (EPA Victoria, 2002).

7.2.2 Risks

The use of wastewater for irrigation has been most successful in urban and peri-urban areas, where wastewater is easily available and reliable, generally free of charge, and where there is a market for agricultural produce. Sometimes, storage of wastewater may be necessary to provide partial treatment or because supply trends may not match the demand (e.g. seasonal variabilities).

Collected wastewater will go through certain treatment procedures at the wastewater treatment plant level prior to being applied on the field or used for any other purposes. Although required treatment levels vary according to the wastewater source (type and concentration of contaminants) and the expected use (crop type, harvesting method, etc.), secondary treatment is often considered sufficient for use in agriculture.

The treated wastewater and/or the reused water will then need to go through appropriately controlled application techniques, and potentially additional treatment if required.

> **Water reuse for agriculture can have significant health benefits, including increased food security and improved nutrition**

HEALTH RISKS

Wastewater use constitutes a risk for the health of farmers, food chain workers and consumers, due to possible microbial and chemical contamination. The use of low-cost labour is a common practice among farmers using wastewater, and much of this work is carried out by women. As a result, they face higher health risks, including pathogen exposure, and potential transmission to family members (Moriarty et al., 2004).

Different approaches have been proposed for the mitigation of health risks. Many approaches have focused on water quality and strict regulations at the point of use, making wastewater treatment a central element for water reuse (Asano and Levine, 1998; Mara and Cairncross, 1989). In the European Union, for example, the Aquarec project proposes seven (treatment-based) quality categories for different types of reuse, with microbial and chemical limits for each category (Salgot et al., 2006).

However, in low-income countries, strict water quality standards for reuse are often perceived as unaffordable and therefore fail in practice. *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture* (WHO, 2006a) acknowledge the potential health risks of wastewater with no or inadequate treatment, and the necessity to reduce such risks. The guidelines propose the use of a number of barriers (multiple-barrier approach) to protect public health along the sanitation and food chains, from wastewater generation to consumption, instead of focusing only on the quality of wastewater at its point of use (see Box 7.1).

ENVIRONMENTAL RISKS

While using treated wastewater and optimizing nutrient input to wastewater-irrigated soils may have multiple environmental benefits, there are some environmental risks associated with the use of untreated or partially treated wastewater in irrigation. These risks include soil contamination, groundwater pollution and surface water degradation.

Trading partially treated urban wastewater (for irrigation) in exchange for access to freshwater sources (for other uses in urban and peri-urban areas) is one approach which can contribute to an overall better management of water resources and reduce negative health and environmental impacts (Hanjra et al., 2012).

The mobility of contaminants and their ability to accumulate aggravate the threat they pose to the environment and to society.

Soil: Wastewater for irrigation adds nutrients, dissolved solids, salts and heavy metals to the soil. Over time, excessive amounts of these elements may accumulate in the root zone with possible harmful impacts on soil. The long-term use of wastewater could result in soil salinity, waterlogging, breakdown of soil structure, overall reduction in productive capacity of soil and lower crop yields. Impacts depend on factors such as the source, use intensity, and composition of wastewater, as well as soil properties and the crops' own biophysical characteristics.

Groundwater: The use of wastewater has the potential both to recharge groundwater aquifers (positive externality) and to pollute groundwater resources (negative externality). Percolation of excess nutrients, salts and pathogens through the soil may lead to the degradation of groundwater. However, the actual impact will depend on a range of factors, including the scale of wastewater use, the quality of the groundwater, the depth to the water table, soil drainage and soil characteristics (e.g. porous, sandy). In irrigated areas with shallow groundwater tables, the impact of irrigation with inadequately treated wastewater on groundwater quality is likely to be substantial.

Surface water: When runoff from wastewater irrigation systems drains into surface water, particularly small confined lakes and water bodies, the remains of nutrients may cause eutrophication, particularly if phosphates in the orthophosphate form are present. Imbalances in the plant and microbiological communities of water bodies may in turn affect other higher forms of aquatic life and reduce biodiversity. If these water bodies serve local communities, the ecological impacts can be translated into economic impacts.

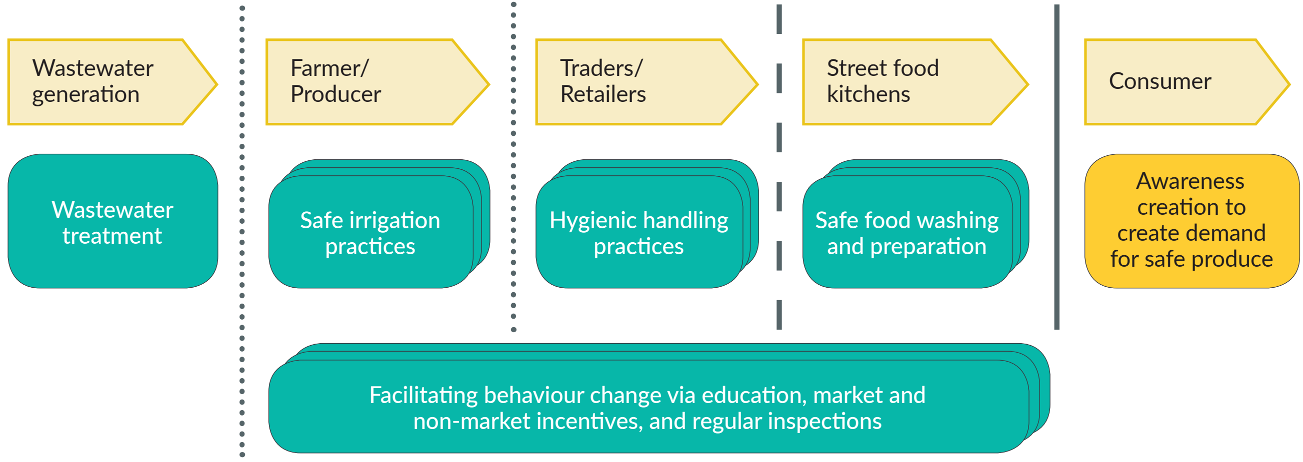
> **The multiple-barrier perspective goes beyond irrigation water quality to also address post-harvest contamination concerns by placing barriers at critical control points along the food production chain**

BOX 7.1 A MULTI-BARRIER APPROACH FOR REDUCING HEALTH RISKS FROM WASTEWATER IRRIGATION

The *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture* (WHO, 2006a) set out a comprehensive risk assessment and management approach to protect public health, seeking to maximize the health benefits of safe water reuse (WHO, 2010). The sanitation safety planning manual (WHO, 2016b) provides practical step-by-step guidance on implementing the risk assessment and management approach.

The multiple-barrier perspective goes beyond irrigation water quality to also address post-harvest contamination concerns by placing barriers at critical control points along the food production chain (see Figure 7.1a). These barriers aim to minimize risks and can be collectively effective even if one fails. This approach is applied in both low-income countries, where irrigation with untreated wastewater is common and wastewater treatment is limited, and developed countries having adopted the hazard analysis and critical control points (HACCP) principles (Ilic et al., 2010).

Figure 7.1a The multi-barrier approach for reducing consumption-related risks along the food chain, as applied in wastewater irrigation.



Source: Amoah et al. (2011, Fig. 1, p. 3).

The approach has been applied in Jordan, where the planned use of wastewater has been promoted since 1977 and where over 90% of treated wastewater is currently being used for irrigation. To deal with health concerns and limited monitoring capacities, the Jordanian authorities introduced national guidelines for irrigation water quality in 2014. As part of the 2016–2025 National Water Strategy, the national guidelines adopted the more flexible health-based target approach described in the WHO 2006 Guidelines (MWI, 2016a).

Contributed by WHO.

CHAPTER 8

UNEP | Birguy M. Lamizana-Diallo and Carla Friedrich

With contributions from: Manzoor Qadir (UNU-INWEH); Javier Mateo-Sagasta and Mathew MacCartney (IWMI); Maite M. Aldaya (Water Observatory, Botín Foundation and Public University of Navarra); and Paul Ouedraogo (Ramsar Convention)

ECOSYSTEMS

Combined sewer overflow treatment wetlands in Washington, Indiana (USA) designed by Lochmueller Group

This chapter examines the role of ecosystems in wastewater management and the use of wastewater for enhancing ecosystem services.

Wastewater, when improperly managed, can have detrimental effects on ecosystems. However, there are numerous opportunities to create synergies between ecosystem services and wastewater management. These interactions can be examined from two perspectives. First, ecosystem services can contribute to wastewater treatment as an alternative or supplement to conventional water treatment systems. The water purification process provided by aquatic and terrestrial ecosystems can supply clean water suitable for drinking, industry, recreation, and wildlife habitat. Second, the resources embedded in wastewater – including water, nutrients and organic carbon – can under appropriate circumstances be used for ecosystem rejuvenation and remediation, enhancing ecosystems services, with major benefits for economies and societies.

8.1 The role and limits of ecosystems in wastewater management

There is a clear link between sustainable wastewater management and healthy ecosystems, and if managed well, this relationship can be mutually beneficial. 'Green infrastructure' (GI) refers to natural (e.g. riparian buffers, wetlands and mangroves) or semi-natural ecosystems (e.g. constructed wetlands, rain gardens, bio-retention ponds), which can provide services such as sediment filtration and pollution removal, comparable to certain functions of 'grey infrastructure' (e.g. conventional piped drainage and water treatment systems). The GI approach relies on the provision of ecosystem services to deliver primary water and wastewater management benefits, accompanied by a wide array of secondary co-benefits (e.g. carbon sequestration, biodiversity protection, recreation), in a cost-effective and sustainable manner (UNEP-DHI/IUCN/TNC/WRI, 2014). Protecting and restoring these GI systems benefits human society and contributes to healthy ecosystems.

Riparian buffers are vegetated areas next to water resources that act as filters and protect water quality, provide bank stabilization, and aquatic and wildlife habitat (see Table 8.1) (Lowrance et al., 1995).

Natural ecosystems are known as the kidneys of the environment, removing pollutants (see

Table 8.1 Effects of riparian buffers of different sizes on the reduction of sediment and nutrients from field surface runoff

Buffer width (m)	Buffer type	Sediment			Nitrogen			Phosphorus		
		Input (mg/l)	Output (mg/l)	Reduction (%)	Input (mg/l)	Output (mg/l)	Reduction (%)	Input (mg/l)	Output (mg/l)	Reduction (%)
4.6	Grass	7 284	2 841	61.0	14.1	13.6	4.0	11.3	8.1	28.5
9.2	Grass	7 284	1 852	74.6	14.1	10.9	22.7	11.3	8.6	24.2
19.0	Forest	6 480	661	89.8	27.6	7.1	74.3	5.0	1.5	70.0
23.6	Grass/Forest	7 284	290	96.0	14.1	3.5	75.3	11.3	2.4	78.5
28.2	Grass/Forest	7 284	188	97.4	14.1	2.8	80.1	11.3	2.6	77.2

Source: Lowrance et al. (1995, Table 6, p. 30).

> **Wastewater, when improperly managed, can have detrimental effects on ecosystems. However, there are numerous opportunities to create synergies between ecosystem services and wastewater management**

BOX 8.1 NAKIVUBO WETLAND: A RECIPIENT OF MUCH OF KAMPALA'S (UGANDA) DOMESTIC AND INDUSTRIAL WASTEWATER

The Nakivubo Wetland directly receives untreated wastewater from approximately 100,000 households and several industries in Kampala, neither of which are serviced by the main sewage system. The 5.3 km^2 wetland also receives the effluent of the city's main wastewater treatment plant.

Murchison Bay and Lake Victoria are protected from the effects of sewage by the wetland, which plays a purification role. Since the intake for Kampala water supply lies only 3 km from the wetland's main outflow canal, this protection is vital. The economic value of water purification services of the Nakivubo Wetland has been estimated at between US$980,000 and US$1,808,000 per year, with additional co-benefits totalling US$200,000 per year from crop cultivation, papyrus harvesting, brick making and fish farming (De Groot et al., 2006).

Contributed by Paul Ouedraogo (Ramsar Convention).

Box 8.1), regulating water flow and storing sediment. They can be very effective and economical in terms of providing wastewater treatment services, provided that these ecosystems are healthy, the pollutant load (and types of contaminants) in the effluent is regulated, and the pollution-carrying capacity of the ecosystem is not exceeded. There are natural limits to the assimilative capacity of ecosystems, beyond which they are threatened and can no longer perform a purifying role. Once the concentration of contaminants in runoff reaches critical thresholds, there is a risk of abrupt and irreversible environmental change (Steffen et al., 2015).

Constructed wetlands and pond systems are recognized as a reliable wastewater treatment technology (see Box 8.2). In these systems, the planted vegetation greatly increases the surface contact area, which helps remove contaminants along the filter bed consisting usually of a combination of sand and gravel.

8.2 Planned use of wastewater for ecosystem services

Water reclamation and reuse are no longer a luxury but a must, particularly in water-scarce countries, where many cities and environmental agencies already use partially treated wastewater to create artificial lakes or wetlands, recharge depleted groundwater, restore natural wetlands or irrigate golf courses, parks and gardens (see Table 8.2). In addition to landscape irrigation, reclaimed water has been used to manage natural wetlands in Spain and Mexico (Otoo et al., 2015) to make sure that water levels are maintained even in periods of drought.

The planned use of treated and partially treated wastewater for ecosystem services is relatively recent. It can increase resource efficiency and provide benefits to ecosystems through:

- Reducing freshwater abstraction;
- Recycling and reusing essential nutrients, thereby reducing the fertilizer use and GHG emissions;
- Minimizing water pollution and maintaining the quality of the river water at a sufficient level for fisheries and other aquatic ecosystems to thrive; and
- Recharging depleted aquifers for various beneficial uses, such as indirect potable reuse (IPD) (see Sections 16.1.2 and 16.1.5).

Table 8.2 Examples of using treated wastewater for supporting ecosystem services

Name of the reuse project	Country	Type of water reuse	Drivers of water reuse	Purpose of water reuse	Technology for wastewater treatment
Quighe and BeiXiaoHe Water Reclamation Plant	China	Greening of landscapes	Water cost savings; insufficient alternative water resources	Landscape irrigation; groundwater recharge	Micro-filtration; reverse osmosis
Marrakech Wastewater Treatment Plant	Morocco				
Sulaibiya Wastewater Reclamation Project	Kuwait				
Jonan Three River Project	Japan	Restoration of wetlands and reservoirs	Drying up of natural water resources – restoration of water channels, lakes and rivers	Water channels and river restoration	Activated sludge; sand filtration; advanced treatment with nutrient removal process
Texcoco Lake	Mexico				

Source: Adapted from Otoo et al. (2015, Table 10.2, pp. 177–180).

BOX 8.2 CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT, INDIANA, USA

In Washington, Indiana (USA), combined sewer overflows (CSOs) were regularly contaminating local waterways. The city constructed an artificial wetland to process wastewater, which saved the city over US$26 million compared to the estimated cost of building a conventional treatment system, as well as saving US$1.6 million annually in operational costs. Water discharged from the constructed wetland system has exceeded the water quality standards for the city's wastewater treatment plant, and wildlife has returned to the local waterways since the system's construction.

Source: PR Newswire (2013); UNEP-DHI/IUCN/TNC/WRI (2014); and City of Washington, personal communication (2016).

Although valuation of treated wastewater use for ecosystem services reveals favourable environmental and economic benefits (see Box 8.3), functional markets for many of the ecosystem services are currently embryonic or non-existent (Qadir et al., 2015a).

Given the degradation of natural habitats for waterbirds, constructed wetlands provide a legitimate alternative.

BOX 8.3 RECREATIONAL OASIS CREATED BY TREATED WASTEWATER IN LIMA, PERU

In a city of dust and sand, parks and gardens can positively impact human well-being. Huascar Park, a multi-purpose recreational park, receives its water from one of Lima's 15 wastewater treatment plants. Huascar Park combines wastewater treatment and a public park, which is a win-win situation as it optimizes resource recovery in an urban area and provides benefits for ecosystems. The partially treated wastewater supplies water and some nutrients to the park, which are extremely valuable in Lima where soils are low in moisture and fertility. It also saves freshwater for other uses and improves the availability of nutrients in the soils for vegetation, thereby creating a recreational 'oasis' in the middle of the Peruvian capital.

There is an important local ecosystem service provided, as the green area provides an environment conducive for the relaxation and recreation of the park visitors, thereby supporting their mental and physical health.

Contributed by Manzoor Qadir (UNU-INWEH).

> Governments and companies have traditionally focused on meeting emission standards – effluent or discharge standards – without considering the ambient standards from the ecosystem standpoint

8.3 Operational and policy aspects

Reducing pollution caused by untreated wastewater discharges and increasing the use of treated wastewater requires concerted efforts, which need to be done through integrated, full-life cycle ecosystem management and resource efficiency objectives. Policies and approaches that recognize wastewater as a resource and highlight the strong linkage between ecosystem services and human well-being are also required.

The implementation of ambient water quality standards is key to the prevention of negative environmental impacts and the conservation of natural ecosystems. Ambient standards refer to the capacity of natural ecosystems to absorb or assimilate environmental pollution. They are measured as the maximum allowable amount of a substance in a water body, given as a concentration. Since the ambient standards can be set at differential levels for varying locations, it is possible to use them to reduce the total maximum load and protect valuable ecosystems in a way that would not be possible using emission controls (Markandya et al., 2001) (see Box 8.4). Although ambient water quality standards often exist in national legislation, they do not exist for all substances and all places (Hoekstra et al., 2011). When they do exist, the capacity to effectively enforce them is often lacking, especially (but not only) in developing countries.

BOX 8.4 ADDED VALUE OF THE AMBIENT WATER QUALITY STANDARDS IN COMPARISON WITH EMISSION STANDARDS

Governments and companies have traditionally focused on meeting emission standards – effluent or discharge standards – without considering the ambient standards from the ecosystem standpoint. Meeting emission standards is one thing, but looking at how effluents influence the assimilation capacity of water bodies is another. Meeting effluent standards – in terms of concentration of chemicals in the effluent – can simply be done by using more water to dilute the effluent before disposal, which might be helpful to meet effluent standards. However, it does not reduce the total load of chemicals added to the environment and the related impact on the ecosystems, not to mention the related increase in overall water use.

Source: Hoekstra et al. (2011).

Contributed by Maite M. Aldaya (Water Observatory, Botín Foundation and Public University of Navarra).

PART III

REGIONAL ASPECTS

CHAPTER 9

UNESCO Multisectoral Regional Office in Abuja | Simone Grego and Oladele Osibanjo

AFRICA

Optimizing water reuse and efficiency

This chapter examines the critical challenges of Africa's rapidly growing urban settlements and the opportunities provided through wastewater use.

9.1 Water and wastewater in Sub-Saharan Africa

Africa is home to 15% of the world's population, but has only 9% of global renewable water resources, unevenly distributed across the region (Wang et al., 2014). The gap between water availability and water demand is growing fast, especially in cities, where the urban population is expected to nearly quadruple by 2037 (World Bank, 2012). The improvement of living standards and the change in consumption patterns are contributing to this growth in water demand. On the other hand, water availability is decreasing due to competing demands from agriculture, mining and industry, and deteriorating water quality. Large numbers of people are dependent on groundwater as their primary or alternate source of water, but pollution and over-extraction threaten groundwater resources (World Bank, 2012).

In Sub-Saharan Africa, out of over a billion people, there are still 319 million people without access to improved drinking water sources. For sanitation, the picture is even gloomier, as 695 million people do not have basic sanitation and not a single Sub-Saharan African country has met the MDGs target regarding sanitation (UNICEF/WHO, 2015).

Mining, oil and gas, logging, and manufacturing represent the main industries in the region. All of these produce wastewater, which is often released into the environment with minimal or no treatment. For example, in Nigeria, less than 10% of industries reportedly treat their effluents before discharging them into surface waters (Taiwo et al., 2012; Ebiare and Zejiao, 2010). Moreover, where stabilization ponds exist, pollutant concentrations observed in the effluent were sometimes five times greater than those observed in Europe (Li et al., 2011).

Agricultural runoff containing agro-chemicals and plant and livestock wastes are a contributing source of pollution to water bodies. For example, a link has been established between the periodic eutrophication of the Oyun Reservoir in Offa, Kwara State, Nigeria, and the runoff of phosphate fertilizers from nearby farms and from cow dung washing from the watershed into the reservoir (Mustapha, 2008).

In most African cities, rain washes municipal solid wastes and other pollutants into rudimentary drainage systems and subsequently, into nearby rivers (cf. Taiwo, 2011) and groundwater. The situation is further aggravated by the weak enforcement of, and non-compliance with, town planning principles and regulations (Osibanjo and Majolagbe, 2012).

While agricultural and industrial wastewaters are recognized pollution sources in the region, the focus of this chapter is mainly on urban wastewater, as the latter is central to the new opportunities that could arise from improved management, in the context of accelerated urban growth.

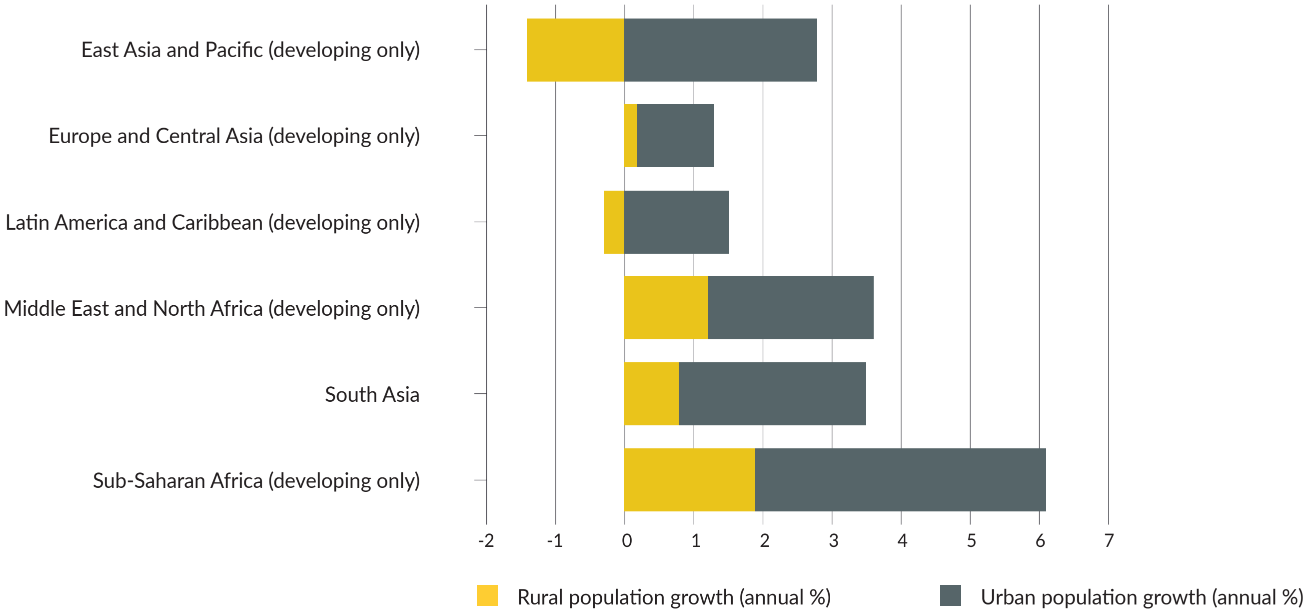
9.2 Critical challenges

9.2.1 Urban settlements

One of the main challenges related to wastewater in Africa is the overall lack of infrastructure for collection and treatment. Combined with high organic loads, unregulated waste input, power outages, increasing wastewater flow rates, high energy costs and lack of re-investments (Nikiema et al., 2013), this results in the pollution of already limited surface and groundwater resources.

In urban settings, sewer collection tends to be limited, and connections from houses and facilities to municipal sewerage are insufficient. Where infrastructure exists, improper operation, poor maintenance and lack of skilled professionals severely limit the effectiveness of the treatment process, leading to the high concentration of pollutants found in the environment.

Figure 9.1 Urban and rural population (% annual growth), 2013



Source: Based on data from the World Bank (n.d.).

In existing waterworks, the lack of stable financial support impedes the maintenance and upgrade of treatment facilities and the purchase and use of adequate monitoring instruments (Wang et al., 2014; Nikiema et al., 2013). In Addis Ababa, for example, the Kaliti treatment plant, initially designed to serve 50,000 people, was serving less than 13,000, which was attributed to a lack of investment in connecting houses to the sewerage pipelines, resulting in a low connection rate. It has been calculated that, in 2009, less than 3% of the wastewater produced by the town reached wastewater treatment facilities (Abiye et al., 2009).

Another challenge hampering the ability of African countries to manage wastewater is the insufficient capacity for effective monitoring of wastewater before and after treatment. In Nigeria, for example, a recent study (UNESCO, 2016a) indicates that only a few laboratories in the country are able to detect emerging pollutants.

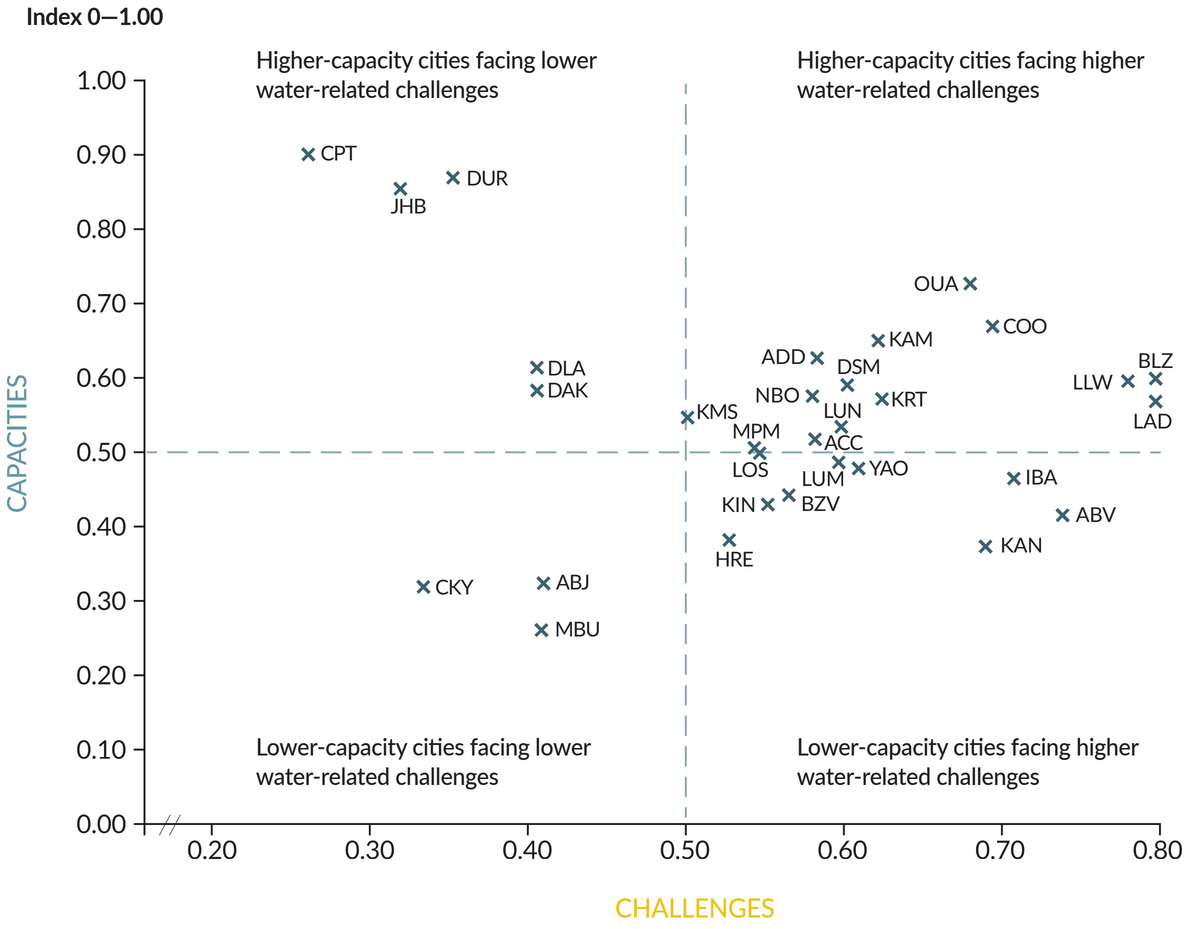
9.2.2 Governance and data needs

Poor governance, including ineffective policies and institutions, lack of enforcement, corruption, insufficient infrastructure and a shortage of investments in human capacity, contributes to ongoing water and wastewater quality problems (UNEP, 2010).

A critical issue, which limits the possibility of establishing adequate policies for water quality, is the lack of available data about wastewater. In Sub-Saharan Africa, little quantitative data are available about wastewater generation, treatment, use and quality. Comprehensive information is available only for Senegal, Seychelles and South Africa, with data from Seychelles and South Africa dating back to early 2000 (Sato et al., 2013).

In addition, existing laws and legislation for the water sector at all the tiers of government usually do not take wastewater into consideration. In Nigeria, for example, there is little to no mention of wastewater in most of the federal and state laws (Ajiboye et al., 2012; Goldface-Irokalibe, 1999 and 2002; Goldface-Irokabile et al., 2001). Enforcement of regulation (i.e. for the industries connected to the sewerage) is almost non-existent in most countries, directly affecting water quality downstream.

Figure 9.2 Urban water management challenges versus institutional and economic capacities



Source: World Bank (2012, Fig. 1, p. 5).

* Notes: Cities abbreviations: ABJ, Abidjan, Cote d'Ivoire; ABV, Abuja, Nigeria; ACC, Accra, Ghana; ADD, Addis Ababa, Ethiopia; BLZ, Blantyre, Malawi; BZV, Brazzaville, Congo; CKY, Conakry, Guinea; COO, Cotonou, Benin; CPT, Cape Town, South Africa; DAK, Dakar, Senegal; DLA, Douala, Cameroon; DSM, Dar es Salaam, Tanzania; DUR, Durban, South Africa; HRE, Harare, Zimbabwe; IBA, Ibadan, Nigeria; JHB, Johannesburg, South Africa; KAN, Kano, Nigeria; KIN, Kinshasa, D.R. Congo; KMS, Kumasi, Ghana; KRT, Khartoum, Sudan; LLW, Lilongwe, Malawi; LAD, Luanda, Angola; LOS, Lagos, Nigeria; LUN, Lusaka, Zambia; MBU, Mbuji-Mayi, D.R. Congo; MPM, Maputo, Mozambique; NBO, Nairobi, Kenya; OUA, Ouagadougou, Burkina Faso; YAO, Yaounde, Cameroon.

** Note on methodology: This figure presents an index that categorizes cities in two dimensions: water-related challenges and institutional and economic capacities. For each dimension, a number of variables were identified, for which indicators were then selected. For the water-related challenges dimension, indicators were selected for the following variables: urbanization challenges, solid waste management, water supply services, sanitation services, flood hazards, and water resources availability. For the institutional and economic capacities dimension, indicators were selected for the following variables: country policies and institutions, economic strength, water-related institutions, and water utility governance. Indicators were normalized, thus units value vary from 0 to 1. Indicators were assigned equal weights and aggregated for each dimension.

9.2.3 Rapid urbanization

In 2013, the annual growth rate of the urban population (see Figure 9.1) in the developing countries of Sub-Saharan Africa (6%) was three times higher than the rural one (2%). The ratio of people living in urban areas in Africa is projected to increase from 40% to 45% between 2015 and 2025 (UNDESA, 2014). These figures suggest that there will probably be a massive increase in wastewater production in African cities (World Bank, 2012).

African cities are growing quickly, and their current water management systems cannot keep up with the growing demand. It has been estimated that half of the urban infrastructure that will make up African cities by 2035 has yet to be built (World Bank, 2012). This scenario poses several challenges and, at the same time, offers opportunities to break away from past (inadequate) water management approaches and to shift to innovative water management solutions, such as integrated urban water management (IUWM), which includes the use of treated wastewater to help meet increasing water demand.

Limited human, financial and institutional capacities related to water management pose challenges for African cities. Although the main challenges in terms of magnitude exist in the larger cities, these are also relatively better-placed in terms of institutional and economic capacity (see Figure 9.2) to address the problems through economies of scale. Most smaller cities lack this advantage and clearly need to focus on capacity-building as a necessary step towards improving their water and wastewater management systems.

> **The gap between water availability and water demand is growing fast, especially in cities, where the urban population is expected to nearly quadruple by 2037**

BOX 9.1 WASTEWATER USE IN KUMASI AND ACCRA, GHANA

Ghana provides a good example of urban and peri-urban agriculture developing through informal irrigation with untreated wastewater from streams and drains. In Kumasi and Accra, where the central wastewater treatment plants are barely functional, wastewater is regularly used to irrigate crops. This practice, common in urban centres in many countries of Africa, provides food for the population, offers employment and alleviates poverty for a number of Ghanaians, and also helps to preserve freshwater resources.

In Accra, farmers irrigate more than 15 kinds of vegetables with untreated wastewater. Urban plot sizes vary between 22 and 3,000 m^2 per farmer. Year-round irrigated vegetable farming can achieve average annual income levels of US$400–800 per farmer. The annual market value for production is estimated at US$14 million and around 200,000 urban dwellers from all classes benefit from this production. The cultivated land in Kumasi is estimated to cover 115 km^2, which is twice the total area reported under formal irrigation in the whole country.

There are, however, public health concerns, in particular regarding microbial contamination of these agricultural products. Analysis of vegetables sold in the markets has shown the presence of faecal coliforms and helminth eggs (Keraita and Drechsel, 2004).

Source: Bahri et al. (2008).

9.3 The way forward

9.3.1 Wastewater use in urban and peri-urban farms

The value of wastewater as an untapped resource is widely recognized, even in the absence of national policies regulating water reuse in many African countries. Several urban and peri-urban farmers are switching from traditional freshwater irrigation to wastewater irrigation. This is exemplified by the untreated wastewater irrigation business in Kumasi and Accra, Ghana (see Box 9.1), where wastewater is used to irrigate crops and to produce vegetables. While this creates opportunities for business and improved livelihoods, it has serious health implications for customers and farmers (Keraita and Drechsel, 2004; Drechsel et al., 2010).

In the region, there are several examples of sludge recovery for agricultural use, creating opportunities for the improvement of livelihoods for farmers whilst helping to reduce the quantity of sludge released into the environment. A pilot composting plant was set up in Kumasi, Ghana, and its operations were monitored for 12 months (Mensah et al., 2003). The positive results, including farmers' acceptance to use the composts as fertilizer, indicate that nutrient recovery from sludge is a viable option to reduce the impact of wastewater on water quality and to improve the livelihoods of farmers in urban and peri-urban areas.

> Strong advocacy is needed to convince policy-makers and members of the political class of the phenomenal 'cost of inaction' in terms of socio-economic development, environmental quality and human health

9.3.2 Treated wastewater use

Namibia and South Africa provide two good examples of using wastewater which, when properly treated, can be a safe source of water for drinking and industrial purposes. Box 16.1 shows how in Windhoek, Namibia, wastewater is treated to meet drinking water quality standards, while Box 9.2 describes how wastewater is being recycled in industry.

9.3.3 Creating an enabling environment for positive change

Sub-Saharan Africa can address the strong growth in water demand that is expected for 2030 and meet the SDG 6, provided it starts addressing its current water challenges now and embraces the opportunities that improved wastewater management can provide. This move will require a better governance structure, effective institutions and policies, better infrastructure for wastewater collection and treatment, and better maintenance of this infrastructure. Increased human and institutional capacity-building for wastewater treatment, monitoring and data management, a stronger regulatory framework, and enforcement and compliance monitoring are also critically important.

In order to achieve success in the implementation of the foregoing elements, a strong political will is necessary. Therefore, strong advocacy is needed to convince policy-makers and members of the political class of the phenomenal 'cost of inaction' in terms of socio-economic development, environmental quality and human health.

Sub-Saharan Africa can address the strong growth in water demand that is expected for 2030 and meet the SDG 6, provided it starts addressing its current water challenges now and embraces the opportunities that improved wastewater management can provide

Finally, the establishment of adequate financial mechanisms is a key element. Investors can be reluctant to finance water infrastructure projects, demanding high upfront payments and long development periods. Different options for financing wastewater management should hence be explored with national governments, such as payment of water/wastewater levies, participation by the private sector through investment in effective low-cost best available technologies and public–private partnership (see Chapter 15). Donor support should be sought for pilot/demonstration projects of innovative business/delivery models, as well as cost-effective and proven innovative technologies.

BOX 9.2 WASTEWATER RECYCLING IN THERMAL POWER GENERATION, SOUTH AFRICA

South Africa has been pioneering the internal treatment and recycling of wastewater in industries since 1980. This practice has the advantage of reducing both the demand for, and the amount of effluent discharged.

ESKOM is the main South African electricity public utility, and one of the largest in Africa. Large quantities of water are used in its inland thermal power plants, mainly for cooling purposes, with production of substantial amounts of "blow-down" water (i.e. the water that is drained from cooling equipment). This water cannot be released untreated, due to its high salinity and the presence of pathogens and chemical additives.

In the early 1980s, ESKOM began installing reverse osmosis plants to treat blow-down water. Currently, in the Lethabo Power Station, in Sasolburg, Free State, a reverse osmosis plant is installed with a total capacity of 12 million litres per day. A part of this clean water is returned to the concentrated cooling water system and another part is used as feed water for the ion exchange process – another desalination process. The water from the ion exchange process has very low levels of total dissolved solids (TDS) and is reused in the plant.

Source: Schutte (2008).

CHAPTER 10

UNESCWA | Carol Chouchani Cherfane

With contributions from: Ali Karnib (UNESCWA) and Manzoor Qadir (UNU-INWEH)

THE ARAB REGION

Miyahuna Wastewater Treatment Plant in Amman (Jordan)

This chapter addresses the production, collection and treatment of wastewater in the Arab region, with a special focus on political frameworks promoting different uses of treated wastewater.

10.1 Context

The Arab region is the driest in the world, with 18 out of 22 Arab countries falling below the water poverty line of 1,000 m^3 per capita in 2014 (AQUASTAT, n.d.b). The use of safely treated wastewater has become a means for increasing water availability in several Arab states and has been included as a core component of water resources management plans at the regional and national levels.

Access to improved sanitation is largely prevalent in the Arab region, but connections to sewerage networks and wastewater treatment facilities remain more limited. Network coverage is generally provided in larger urban centres, while septic tanks and cesspits remain common in rural areas and in the region's least developed countries (UNESCWA, 2013). Off-network sanitation systems, however, complicate the collection and treatment of wastewater and reduce the ability to sustainably manage wastewater as a resource in most areas.

Regional monitoring and reporting on water, sanitation and wastewater services is conducted under the auspices of the Arab Ministerial Water Council through the MDG+ Initiative.[8] The MDG+ data presented in Table 10.1 show that, during the year 2013, 69% of the wastewater collected in Arab States was safely treated, with 46% undergoing secondary treatment and 23% undergoing tertiary treatment. Furthermore, 84% of all wastewater collected in the water-scarce Gulf Cooperation Countries (GCC) underwent tertiary treatment, and 44% of their total safely treated wastewater volume was subsequently used. At the Arab regional level, 23% of the safely treated wastewater is being used, mostly for irrigation and groundwater recharge.

10.2 Challenges

10.2.1 Serving displaced populations and floods

The provision of water, sanitation and wastewater treatment for refugees in camps, informal settlements and host communities in Arab States has become a serious challenge. Jordan hosts over 700,000 registered refugees from Iraq and Syria, of which 90% are living outside of camps (UNHCR, 2016); while in Lebanon, the water infrastructure is struggling to serve the 1.5 million refugees that represent the equivalent of one third of the Lebanese population (UNOCHA, 2016). Conflict and the internal displacement of people in Iraq, Libya, Palestine, Somalia and Syria have also strained the operating capacity of wastewater facilities and damaged sewage networks.

The absence of adequate storm drainage systems and artificial groundwater recharge schemes render treatment plants often inoperable during extreme rainfall events, which are increasing in frequency and intensity due to climate change. Flooding has imposed economic and environmental costs and damage to infrastructure, property and protected areas, as has been experienced on the Socotra Islands in Yemen, the Arabian Gulf, as well as along the Egyptian, Lebanese and Palestinian coasts over the last few years.

10.2.2 Industrial wastewater

Industrial wastewater management is costly and controversial in the region. Chemical and biological effluents from the textile and tannery industries in Egypt, Morocco and other Arab countries affect surface and groundwater supplies, but closing these small-scale businesses threatens traditional livelihoods.

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[8] The MDG+ Initiative is a regional, intergovernmental initiative that collects country-level data from National Monitoring Teams, comprised of the national ministry responsible for water and wastewater utilities, and statistical offices in each Arab State. The initiative collects data on access to water supply, sanitation and wastewater treatment services in the Arab region. The wastewater indicators measured by the MDG+ Initiative clarify the quantity of wastewater treated by level, the quantity of treated wastewater used and for what purpose, and the tariff applied on sanitation services. Detailed descriptions and methods of calculating the MDG+ indicators can be found in UNESCWA (2013).

> **At least 11 out of 22 Arab States have adopted legislation permitting the use of treated wastewater**

Table 10.1 Volume of collected wastewater, wastewater treatment and use (million m^3 per year), 2013

State	Volume of collected wastewater	Primary treatment	Secondary treatment	Tertiary treatment	Volume of safely treated wastewater	Volume of treated wastewater used	Treated wastewater use (% of safely treated wastewater)
Gulf Cooperation Council (GCC)							
Bahrain	122.8	0	0	122.8	122.8	38.1	31
Kuwait	n.a.	0	58.0	250.3	308.3	308.3	100
Oman	26.2	0	0	26.2	26.2	20.4	78
Qatar	176.8	0	0	158.7	158.7	115.9	73
Saudi Arabia	1 317.2	0	580.2	736.9	1 317.1	237.1	18
United Arab Emirates	615.7	0.3	11.7	593.6	605.3	397.2	65.6
Mashreq							
Egypt	3 030.4	724.3	2 054.8	57.1	2 111.9	n.a.	n.a.
Iraq*	620.4	0	415.7	0	415.7	0	0
Jordan	130.8	0	130.8	0	130.8	113.3	87
Lebanon	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Palestine*	61.0	0.3	45.3	0	45.3	0	0
Maghreb							
Algeria	1 570.4	0	275.2	0	275.2	19.3	7
Libya*	291.1	0	45.8	0	45.8	14.7	32
Morocco	144.2	38.2	0.1	6.1	6.2	n.a.	n.a.
Tunisia	235.0	0	222.0	6.6	228.6	60.0	26
Least developed countries (LDC)							
Mauritania	0.65	0	0.65	0	0.65	0.12	18
Sudan	18.0	18.0	0	0	0	0	0
Yemen*	159.4	58.1	42.2	22.0	64.3	n.a.	n.a.
TOTAL	**8 520.0**	**839.2**	**3 882.5**	**1 980.3**	**5 562.8**	**1 324.4**	**23**

* Data represent the year 2012.
n.a.: Not available.

Source: Compiled from LAS/UNESCWA/ACWUA (2016).

On a larger scale, brine released from desalination plants includes chemical residues that negatively affect coastal ecosystems. Oily water brought to the surface during oil extraction contaminates aquifer systems and degrades land resources.

10.2.3 Insufficient integration and investment

Despite investments in secondary treatment plants, many facilities are overloaded and produce effluent below the expected quality, due to changing population pressures and the time lag between the design and construction (UNESCWA, 2013). Investment choices are also often made with little regard for the hot and arid climate conditions that characterize the region, which should be considered, particularly when assessing aerobic and anaerobic treatment options. The technical capacity and budgets to operate and maintain secondary and tertiary wastewater facilities also lag behind in some Arab countries. This constrains investment opportunities and lengthens the time required to render the plants operational.

Wastewater master plans can quickly become outdated, given the regional dynamics (see Box 10.1). Institutional arrangements for wastewater management can also be unclear. Moreover, there is often a lack of coordination between national and municipal actors responsible for extending sewerage networks, and water resource managers and water utilities responsible for operating wastewater facilities (see Chapter 3).

10.3 Responses

In 2011, the Arab Ministerial Water Council adopted a regional water security strategy and action plan, which called for the expansion of desalination and the use of treated wastewater and agricultural drainage water as non-conventional water resources that can be developed to offset the water deficit in the Arab region (AMWC, 2011). In tandem, the Council launched the MDG+ Initiative to monitor and report on water supply, sanitation and wastewater services in Arab states, based on a set of region-specific indicators that examine water and wastewater within the context of water-scarce environments (UNESCWA, 2013).

10.3.1 Policy frameworks

At least 11 out of 22 Arab States have adopted legislation permitting the use of treated wastewater, issued by the national institutions responsible for the use and discharge of wastewater, whether it be the ministries responsible for the environment in Kuwait, Lebanon and Oman, health in Iraq, agriculture in Tunisia, housing in Egypt, or the institutes responsible for standards in Jordan and Yemen (WHO, 2006b).

BOX 10.1 NATIONAL STRATEGY FOR THE WASTEWATER SECTOR IN LEBANON

In 2012, the population of Lebanon was estimated at 4.3 million. Out of about 310 million m^3 of wastewater produced annually, an estimated 250 million m^3 came from domestic sources and 60 million m^3 from industry (MEW, 2012).

It is estimated that only 8% of the wastewater generated in Lebanon is treated. About 11% of the population uses safely managed wastewater systems in the governorates of North and South Lebanon, compared to only 7% and 3% in Greater Beirut and the Bekaa, respectively (Karnib, 2016). Most collected wastewater is discharged into surface waters and the Mediterranean Sea. On-site septic tanks have contaminated groundwater resources, such as the Jeita Springs that supply water to Greater Beirut (BGR, n.d.). The harmful impacts of inadequate wastewater collection, transfer and treatment increase health and environmental risks.

The 2012 National Strategy for the Wastewater Sector includes five strategic pillars: i) an integrated and prioritized investment programme for wastewater collection, treatment and use; ii) legal, regulatory and policy measures to set and regulate standards; iii) institutional measures to define responsibilities and to create capacity for service delivery; iv) financial measures for viability and affordable services; and v) measures to optimize private sector participation in the wastewater sector. The implementation cost was estimated at US$3.1 billion for work planned between 2012 and 2020. Unfortunately, the implementation of the strategy was disrupted due to a lack of funding and the instability resulting from political uncertainty and ongoing conflicts in the region.

Jordan and Tunisia address wastewater within the context of their national water policies and plans. Jordan adopted the "Water Substitution and Reuse Policy" in February 2016, which formalizes treated wastewater use as a national policy and includes plans to set tariffs for the use of treated wastewater and blended treated wastewater (MWI, 2016a). This has been complemented by a decentralized wastewater management policy to serve smaller communities (MWI, 2016b) – a significant step as treated wastewater accounts for nearly 15% of available water resources in Jordan (UNESCWA, 2015).

Donor coordination and investment planning in the wastewater sector is well developed in Jordan. The *Jordan Response Plan for the Syrian Crisis 2016–2018* dedicates significant resources to expanding wastewater collection and treatment in host communities in Jordan. The incorporation of energy efficiency and local air pollution measures in wastewater treatment plants has also been planned, as well as efforts to ensure gender-sensitive sanitation facilities in schools and healthcare clinics (MOPIC, 2016). Tunisia has also engaged in an active water reuse programme (see Box 10.2).

10.3.2 Produced water use by the oil industry

Efforts have been made to treat and use water produced during oil extraction. Oman tested the treatment and use of oil-containing wastewater for irrigation as an alternative to injecting the water back into aquifers, contaminating groundwater resources (JPEC, 1999). The de-oiling of produced water was also researched by Sultan Qaboos University in Oman (Pillay et al., 2010), which found that constructed wetlands could also be used to dispose of the treated produced water.

10.3.3 Treated wastewater use for ecosystems and artificial groundwater recharge

Saudi Arabia's investment in an environmentally sensitive wastewater treatment system around Riyadh resulted in the construction of the Wadi Hanifa Wetlands from redirected drainage and treated wastewater. The initiative received the Aga Khan Award for Architecture for the design of the new recreational spaces and the re-emergence of biodiversity in the area (AKDN, n.d.).

Off-network approaches are also being applied that draw on lessons learned from natural ecosystems. In Lebanon, the Litani River Authority successfully tested a constructed wetland for wastewater treatment. Meanwhile, similar nature-based decentralized approaches to wastewater treatment are being adopted in several mountain communities in Lebanon that cannot be accessed by sewage networks (Difaf, 2016).

Treated wastewater is now also being used to support artificial groundwater recharge and water storage in the water-scarce Arab region. In Bahrain, 7% of treated wastewater is used for groundwater recharge (LAS/UNESCWA/ACWUA, 2015). Meanwhile, some Arab States are redirecting stormwater and treated wastewater into aquifers as a way to manage extreme rainfall events and increase water reserves, as was done by Egypt along its Red Sea Coast.

10.3.4 Wastewater to energy

Recovered biogas from wastewater treatment through anaerobic digestion allows for the production of energy (see Section 16.2.2). Recovered biogas in the region is being used for on-site generation of heat and electricity, and could even be used for off-site energy production. The As-Samra Wastewater Treatment Plant, the largest in Jordan, serves 2.27 million people and achieves 80% energy self-sufficiency through a biogas-powered generator supported by an anaerobic sludge digestor (UNESCWA, 2015). The Gabal El Asfar wastewater treatment facility on the east bank of the Nile in Cairo has a processing capacity of more than 1.4 million m^3 per day, and includes a cogeneration plant fuelled by anaerobic sludge digestion that produces up to 65% of the power needed to run the facility (Badr, 2016).

Modular biogas digesters are also being considered for generating and supplying energy to refugee camps and informal settlements in the Mashreq. However, awareness-raising within the local cultural context is needed before application of such approaches is pursued beyond the pilot phase.

BOX 10.2 WATER REUSE IN TUNISIA

Water reuse has been a priority in Tunisia since the early 1980s, when Tunisia launched a nation-wide water reuse programme to increase the country's usable water resources. Most municipal wastewater receives secondary biological treatment through activated sludge, with some limited tertiary treatment also in place.

Restrictions on treated wastewater use to protect public health have received considerable attention and are in line with WHO recommendations (WHO, 2006b). Tunisian regulations allow for the use of secondary treated effluent on all crops except vegetables, whether eaten raw or cooked. Regional agricultural departments supervise the use of safely treated wastewater and collect charges from the farmers. Tunisian farmers pay for irrigation water on the basis of the volume of water required and the area to be irrigated.

While there is strong government support for treated wastewater use, farmers continue to prefer irrigation from groundwater due to social acceptance, regulations concerning crop choices, and other agronomic considerations. Farmers in the arid south have also expressed concerns about the long-term impacts of saline wastewater on their crop productivity and soils. In addition, farmers consider the health restrictions as an impediment to growing high-value crops such as vegetables. To address these challenges, Tunisian policy-makers have sought to improve the coordination and pursue demand-driven approaches to improve the planning of wastewater reclamation and irrigation projects with safely treated effluent (Qadir et al., 2010).

Contributed by Manzoor Qadir (UNU-INWEH).

CHAPTER 11

UNESCAP | Aida N. Karazhanova and Donovan Storey, with contributions from Jayakumar Ramasamy (UNESCO Bangkok Office), Ram S. Tiwaree and Stefanos Fotiou

ASIA AND THE PACIFIC

Community-led meeting on sanitation in Lao PDR

This chapter describes how wastewater is being increasingly recognized as a potential resource for different sectors across the Asia and Pacific region, with co-benefits ranging from climate resilience to by-product recovery.

11.1 Context and challenges

Asia and the Pacific region is experiencing increased competition across key sectors over limited freshwater resources, while an estimated 80–90% of all wastewater produced in the region is released untreated, polluting ground and surface water resources, as well as coastal ecosystems (UNESCAP, 2010) (see Table 11.1). In order to meet future water demands in the region and reduce pollution, water needs to be used more efficiently and wastewater production and discharge improved by using innovative management and technical solutions.

The region's urban population more than doubled between 1950 and 2000 (UNESCAP/UN-Habitat, 2015), creating a huge demand for new and improved wastewater treatment systems. Another challenge for wastewater management in urban areas is related to socio-economic disparities. Slum areas are typically underserved (see Section 5.3), whereas wealthier neighbourhoods generally have better access to wastewater management infrastructure and services. As of 2009, 30% of the region's urban population lived in slums and over half of the regional rural residents still lacked access to improved sanitation, compared to 25% of urban residents (UNESCAP, 2014).

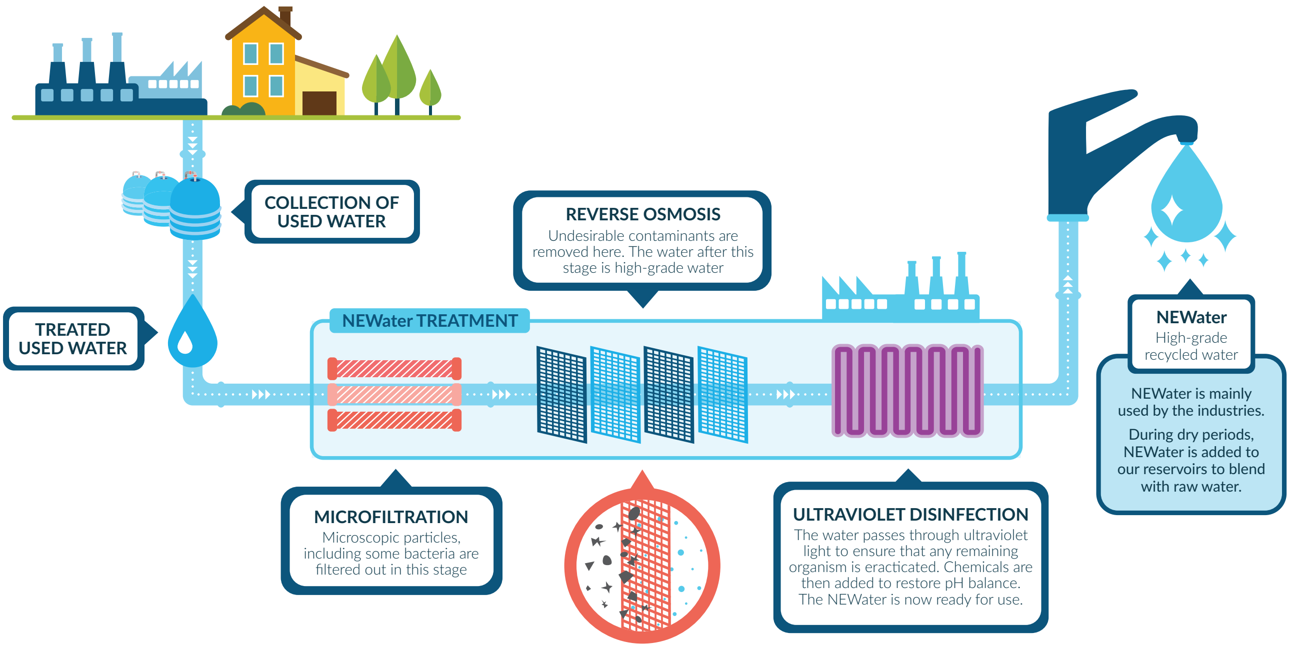
In order to close existing gaps between water demand and available supplies, the region needs to upscale and implement integrated policy frameworks (including through public consultations) that facilitate circular economies and green growth initiatives. Technologies to improve water use efficiency have been commonly adopted in China, Japan and the Republic of Korea. In these countries, wastewater management and water reuse have become an integral part of the water management cycle, including through economic stimulus packages to prevent wastewater discharge and pollution. These practices are also accompanied by enabling financial policies that help create markets for wastewater by-products (including those associated with ecological sanitation (EcoSan) case studies in India and Nepal), which in turn can positively impact access to sanitation services (UNESCAP, 2013). Singapore's NEWater scheme (see Figure 11.1) is enabled by an innovative policy package for water management, adapted to the country's particular geographic, social, political and economic conditions (see Box 16.9).

There is a growing shift from viewing wastewater as an 'unpleasant by-product' of the anthropogenic water cycle towards recognizing its potential as a resource for different sectors. However, most wastewater is still discharged without any treatment (see Table 11.1). For example, the percentage of wastewater release without treatment have been estimated at 77% for Thailand (2012), 82% for Pakistan (2011), 84% for Armenia (2011) and 81% for Viet Nam (2012) (UNESCAP, 2015a). Improving the efficiency of wastewater management would contribute to the achievement of the 2030 Agenda for Sustainable Development in the region.

11.2 Building resilient infrastructure

Natural disasters, 90% of which are water-related, are increasing in frequency and intensity due to climate change (UNESCAP, 2015b). More attention needs to be paid to improving the resilience of physical wastewater infrastructure, such as drains and pipes, and of the drainage systems that can capture runoff during floods and storm events. During floods, which caused an estimated total damage of US$61 billion in the region in 2011 (ADB, 2013), the sewage effluent often mixes with already-contaminated stormwater, creating a

Figure 11.1 General technical scheme of NEWater in Singapore



REVERSE OSMOSIS
Undesirable contaminants are removed here. The water after this stage is high-grade water

MICROFILTRATION
Microscopic particles, including some bacteria are filtered out in this stage

ULTRAVIOLET DISINFECTION
The water passes through ultraviolet light to ensure that any remaining organism is eracticated. Chemicals are then added to restore pH balance. The NEWater is now ready for use.

NEWater
High-grade recycled water

NEWater is mainly used by the industries.

During dry periods, NEWater is added to our reservoirs to blend with raw water.

Source: Courtesy of Singapore's National Water Agency (PUB).

Table 11.1 Countries with the lowest level of wastewater treatment in the Asia-Pacific Region

Country	Wastewater treated (%)	Country	Wastewater treated (%)
Viet Nam	19	Vanuatu	0
Bangladesh	17	Tuvalu	0
Papua New Guinea	15*	Timor-Leste	0
Tajikistan	12	Niue	0
Nepal	12	Nauru	0
Myanmar	10*	Marshall Islands	0
Bhutan	10*	Maldives	0
Cambodia	9	Kiribati	0
Lao PDR	6	Cook Islands	0
Samoa	5*	Afghanistan	0

*Estimate.

Note: The percentage of wastewater treated is very much dependant on the conditions in the countries' largest/larger cities, where the percentage is generally higher, and rarely a reliable indicator of conditions in the smaller urban centres of towns and rural areas, for which data are often lacking.

Source: Adapted from ADB (2013, Appendix 4, p.100).

sanitation crisis and increasing the risk of waterborne diseases. Where urban runoff is a major source of flooding and pollution, as is the case in most cities across the region, there is a great need for new and innovative city planning, including climate-resilient water infrastructure, which can rely on appropriately decentralized water harvesting and collection systems (UNESCAP, 2015a) (see Section 15.5).

There is a great potential for communities to incorporate risk-mitigating infrastructure into new and existing construction projects in order to address these issues. Risk-mitigating infrastructure may include, among others: green roofs, like in Hong Kong, China (Urbis Limited, 2007), restored urban green areas, wetlands and waste-stabilization ponds in Kolkata City (a partly natural partly human-engineered wetland); water-efficient buildings in the Republic of Korea; vertical farming, which is producing large quantities of plants and vegetables inside multi-story buildings in Australia, China, Japan and New Zealand (Despommier, 2011); rainwater catchment systems, in Kiribati; and mangrove belts in Sri Lanka, Thailand and the Pacific Island States. According to one study, green roofs can retain 60–100% of the stormwater they receive, depending on the substrate depth and the quantity and intensity of the precipitation received (Thomson et al., 1998).

11.3 A systems approach to wastewater by-product recovery

By-products from domestic wastewater, such as salt, nitrogen and phosphorus, have potential economic value that can be used to improve livelihoods in the region. In the absence of centralized infrastructure, households that oversee their own sanitation can become energy-independent by utilizing their own waste, thus reducing expenditures for fuel as well as health risks and environmental impacts. Harvesting phosphorus from urine with urine-diverting toilets, like in Australia, China and Japan, also reduces the nutrient load of wastewater effluent and has a great potential for upscaling in the region (UNESCAP/UN-Habitat/AIT, 2015). Biomass (septage) can be used wider as a fertilizer in agriculture, as historically practiced in countries of Central Asia, or can be converted to fuel for cooking or heating with biogas reactors, as seen in cases of rural Cambodia, China, Thailand, Viet Nam, and the Pacific (UNESCAP/UN-Habitat/AIT, 2015), thus reducing water pollution (Schuster-Wallace et al., 2015). Analyses of case studies in South-East Asia have shown that revenues from wastewater by-products, such as fertilizer, are significantly higher than the operational costs of wastewater systems that harvest by-products, providing evidence that resource recovery from wastewater is a viable and profit-producing business model for sustainable practices and economic development (UNESCAP/UN-Habitat/AIT, 2015).

> As of 2009, 30% of the region's urban population lived in slums and over half of the regional rural residents still lacked access to improved sanitation, compared to 25% of urban residents

11.4 Regulatory and capacity needs

Regulations targeting point-source pollution (i.e. industrial contaminants) in cities can help reduce the detrimental effects of urban wastewater in the Asia-Pacific region. Cities often rely on centralized wastewater treatment facilities, which are expensive to develop and maintain, and often cannot meet the immediate needs of urban populations, particularly the poor. In this regard, decentralized wastewater treatment systems, or DEWATS (UNESCAP/UN-Habitat/AIT, 2015), are being increasingly utilized in both rural and urban areas, with a number of benefits (see Section 15.4).

Managing wastewater more effectively and efficiently in the region requires the support of institutions, including greater support for local authorities (GWOPA/UN-Habitat/ICLEI/WWF7/UCLG/WWC/DGI, 2015). Municipalities and local governments often lack the human and financial resources necessary to enforce environmental regulations and improve and maintain water infrastructure and services. As a result, maintenance problems are frequent and widespread, exacerbated by financing and revenue collection deficiencies (UNESCAP, 2015a). More needs to be done across the region to support municipal and local governments in managing urban wastewater and capturing its resource benefits with a view towards achieving the SDG targets, in particular SDG 6 on water and sanitation and SDG 11 on inclusive and sustainable cities.

CHAPTER 12

UNECE | Annukka Lipponen

With contributions from: The Water Team of the GREEN Action Programme Task Force; Organisation for Economic Co-operation and Development; and European Environment Agency

EUROPE AND NORTH AMERICA

Scanning 2000 year-old sewers – Cloaca Maxima in Rome (Italy)

This chapter focuses on responses to wastewater management challenges in Europe and North America, with a particular emphasis on regional legal instruments.

This chapter highlights some pertinent developments in the UNECE region (covering the EU, Balkans, Eastern Europe, the Caucasus and Central Asia as well as North America) related to wastewater, describing the challenges but also some promising responses. The subregions face somewhat different challenges (see Table 12.1).

12.1 Context

Overall, the level of access to sanitation across the region is relatively high, including in the Caucasus and Central Asia, which both met the MDG target for improved sanitation, with access to improved sanitation reaching 95% (UNICEF/WHO, 2015). Development of sanitation services and wastewater treatment across the region is nevertheless uneven, as demonstrated by the Danube Basin (Michaud et al., 2015).

Wastewater treatment in the region has improved during the last 15–20 years. The percentage of the population connected to wastewater collection and treatment in selected subregions of Europe is shown in Figure 12.1. Tertiary treatment has increased gradually but, in South-Eastern Europe and the rest of Eastern pan-Europe, significant volumes of wastewater are still collected and discharged without treatment.

12.2 Challenges

Large parts of the UNECE region are covered by water supply and sanitation systems, but demographic and economic changes have rendered the effectiveness of some of the larger centralized systems suboptimal, as exemplified by several oversized and maladapted systems in parts of the former Soviet Union. The low efficiency of water systems, characterized by high resource use and lack of incentives for efficient water use, is a major issue in Eastern Europe, the Caucasus and Central Asia (UNECE/OECD, 2014), where large volumes of supplied water translate into wastewater, and where all too often only a primary treatment is in place. The water supply and sanitation tariffs are generally too low to cover the costs of operation and maintenance of the services (OECD, 2011a). This poses significant challenges to meeting the infrastructure investment needs and lowers incentives for reasonable usage levels, while raising sustainability concerns (see Box 12.1).

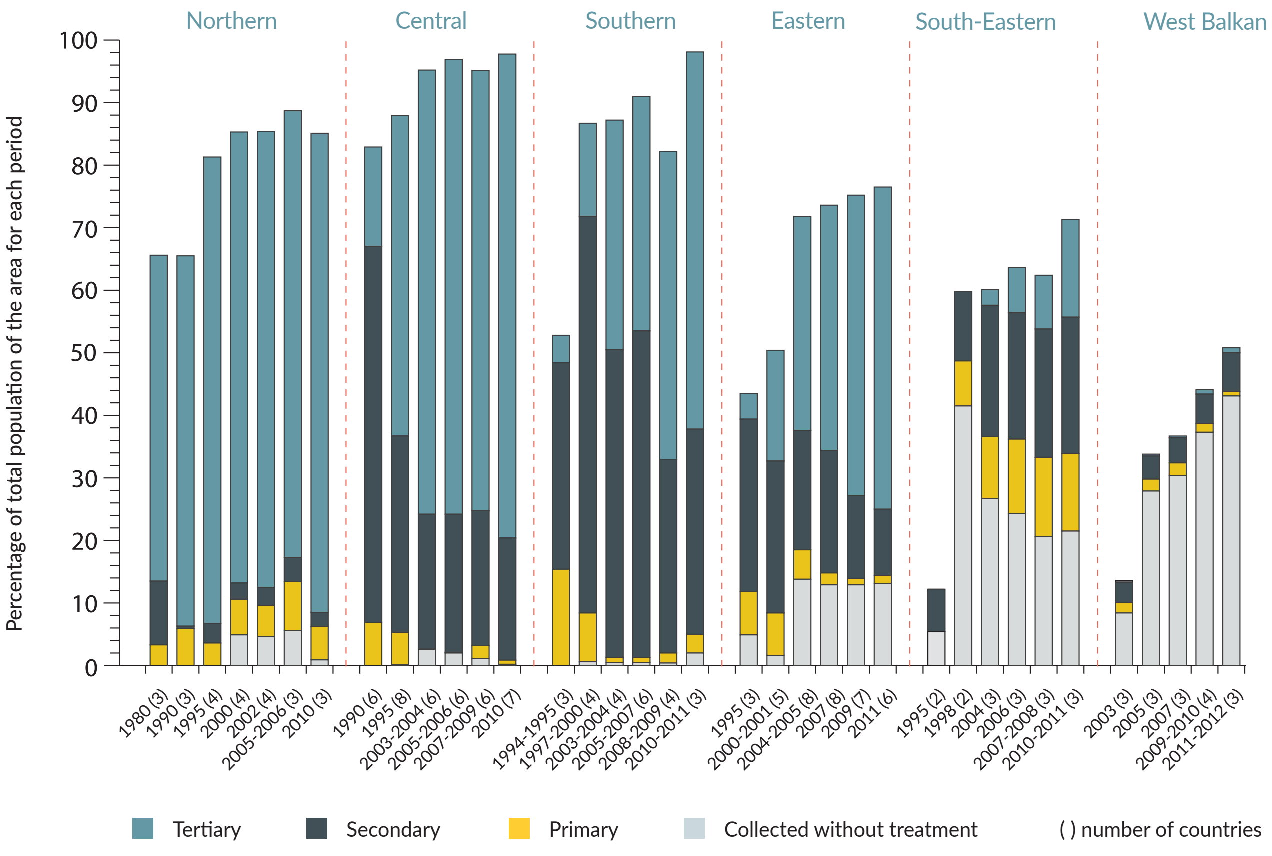
Due to the demographic and economic changes, the wider policy aspirations of resource efficiency (EEA, 2016) and the new knowledge about risks and equity considerations (e.g. urban vs. rural areas, minorities, etc.) (UNECE/WHO, 2013), it has become clear that sanitation and wastewater infrastructure need to be revisited in the region, in order to ensure the adequacy of service as well as the appropriate level and means of treatment. The need to reuse water is becoming more pronounced, especially in areas prone to water scarcity. Investments in treatment and control technologies are increasing in both the USA and the EU (see Box 12.2).

As indirect use of treated wastewater frequently occurs downstream from discharge locations, the performance and adequacy of traditional wastewater treatment systems has come under scrutiny in the UNECE region. New risks related to emerging pollutants (see Box 4.1), including micropollutants, have been acknowledged since the early 2000s (Bolong et al., 2009). Most notable among these are chemical endocrine disruptors, which can exert negative effects on humans, animals and ecosystems. National studies have called for more systematic analyses of their occurrence, transport and effects, in order to develop scientifically well-grounded risk assessments and response actions (Trachsel, 2008; MIE/PWA, 2016).

Table 12.1 Selected challenges and management responses in subregions in the UNECE region (non-comprehensive)

	North America	European Union	South-Eastern Europe and Eastern Europe	Caucasus and Central Asia
Challenge(s)	Water scarcity	Ensure effective removal of emerging pollutants	Compliance with regional standards of wastewater treatment	Addressing pollution from wastewater discharges; extending the coverage of wastewater treatment
Response(s)	Wastewater reuse	Best available techniques/technologies; use of green solutions	Progress with regional legal instruments	Extending and upgrading the infrastructure to more advanced levels of treatment

Figure 12.1 Changes in wastewater treatment in regions of Europe between 1980 and 2012



*UWWTPs = Urban wastewater treatment plants.
Note:
This figure illustrates the percentage population per European region connected to wastewater collection and treatment systems (UWWTPs) over the period 1980 to 2012. In addition, a breakdown by treatment type is portrayed. Numbers in brackets indicate number of countries in the aggregations.

Source: EEA (2013, based on data from Eurostat).

BOX 12.1 MANAGING MUNICIPAL WASTEWATER – INFRASTRUCTURE DEVELOPMENT AND RESTORATION: RECENT TRENDS IN EASTERN EUROPE, CAUCASUS AND CENTRAL ASIA (EECCA) COUNTRIES

In the EECCA countries, a relatively large share of the population is served by centralized urban wastewater collection systems. The coverage in rural areas is much lower, but some countries in the region made significant progress during the 1980s. For example, Moldova built some 650 wastewater treatment plants in rural settlements in this period.

In the 1990s, many sanitation systems in the region degraded due to the decentralization of social infrastructure services to local governments with low fiscal capacity. In Armenia, for example, the total budget of all local governments amounted to just 2% of the national budget, while a village in Moldova had an annual budget equivalent to EUR 10,000 to fund all infrastructure services from school and roads to water supply and sanitation (WSS) (OECD, 2011a; 2013a).

At the same time, the WSS services in the region have also suffered from poor efficiency (oversized systems with high unit costs); inadequate tariff policy and economic regulation; and lack of sustainable business models for operating, maintaining and financing WSS systems, especially in small towns and rural areas. These challenges faced by WSS operators were compounded by the drastic reduction of household income and by growing income disparities, resulting in affordability problems for many households. Such challenges were particularly pronounced in small remote villages (i.e. populations less than 500) where household incomes were lower while unit costs for WSS services were 2–3 times higher than in larger settlements.

However, since 2000, the trend has improved significantly in most EECCA countries, at least in the urban areas (OECD, 2011a), often with support from development partners. Presently, EECCA countries are paying more attention to improving rural sanitation. Progress in these countries has been linked to the revision of outdated technical standards to adjust the capacity of new WSS systems to actual and projected demand for services (OECD, 2012) and to the introduction of sustainable business models for WSS operators, including the 'regionalization' of municipal water utilities, community-based organizations and private operators (OECD, 2013a; 2016).

Contributed by the Water Team of the GREEN Action Programme Task Force, OECD.

> **It has become clear that sanitation and wastewater infrastructure need to be revisited in the region, in order to ensure the adequacy of service as well as the appropriate level and means of treatment**

12.3 Responses

Regional legal instruments have contributed to the general improvement in access to sanitation and reduced impact of wastewater discharges, notably the EU Urban Wastewater Treatment Directive (UWWTD) (see Box 12.3), as well as the UNECE/WHO Protocol on Water and Health (UNECE/WHO, 2016) (see Box 12.4). Some legal instruments in the region provide for technical progress. The notion of 'best available techniques' (BAT), as defined in the EU environmental legislation relating to industrial pollution, also addresses management methods and the environmental impacts. In the chemicals sector, BAT is used as part of an integrated wastewater management strategy, applying a combination of techniques prioritizing those aiming to prevent or reduce the generation of water pollutants and to recover pollutants at the source. In this context, BAT differs from the 'best available technologies' based on which the Parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention; see Section 3.2.1) (UNECE, 1992, entry into force in 1996) are obliged to set limits for wastewater discharges, the latter constituting a set of requirements considering technical aspects (as well as availability), but also financial affordability (UNECE, 2013).

BOX 12.2 OPTIMIZING REUSE POTENTIAL: QUALITY CONTROL OF TREATED WASTEWATER AND EXPLORING ECOLOGICAL SANITATION IN EUROPE AND NORTH AMERICA

Treated wastewater holds significant potential to augment water supplies, even for drinking, and the USA reuses water in major volumes. By allowing detection of chemical and biological contaminants, modern analytical technology and multiple barriers provide the necessary control elements to ensure safe water reuse (Water Science and Technology Board, 2012). A pioneering case of direct potable reuse (DPR) in the USA is the facility of Big Spring, Texas which uses microfiltration, reverse osmosis and UV disinfection. The treated wastewater is mixed with raw water, serving some 250,000 people (Water Online, 2014; Woodall, 2015).

Water scarcity has been an important driver of water reuse, and the matching of water quality to the end use determines the need for treatment. West Basin Water Utility produces five types of “designer” waters for specific uses: irrigation, cooling towers, seawater barrier and groundwater replenishment, as well as two types of boiler feed waters (West Basin Municipal Water District, n.d.). Some water uses are susceptible to be fulfilled with reclaimed water having undergone limited treatment, notably green space maintenance (WssTP, 2013). A lack of risk-based treatment guidelines for greywater and stormwater has been noted to constrain broader use in the USA (National Academies of Science, Engineering and Medicine, 2015). To increase the reuse potential of industrial wastewaters, research and technology development are needed, but also demonstration of the available technologies, as well as combinations of new and existing biological and chemo-physical treatment technologies (WssTP, 2013).

In principle, separation of urine at the source and the recovery of faeces for fertilizer could provide opportunities for both rural households and entrepreneurs, and reduced wastewater treatment could have, for example, energy saving benefits. Interpretations on the use of human faeces and urine vary greatly, even within the EU, from following the same guidelines as for animal manure to prohibiting the practice altogether.

While use of compost from dry toilets and source-separated urine in private gardens may be permitted, use on commercial crops is commonly prohibited (O’Neill, 2015). Driven by aspirations to set up ecological closed-loop processes, ecological sanitation using composting toilets and constructed wetland systems for greywater treatment have been used in ecological settlements (i.e. Allermöhe-East Hamburg, Germany), resulting in the reduction of residents’ water and energy use (Von Muench, 2009). The effective realization of sanitation products’ reuse, and the safe use of the fertilizers it contains require that legislation and policies provide a supportive framework, the related health risks are controlled, related logistical issues are solved (i.e. collection of urine, which will subsequently be turned into a solid form), and that cultural acceptance is achieved (O’Neill, 2015).[9]

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[9] The author wishes to acknowledge inputs received from: Sharon Megdal and Susanna Eden (Water Resources Research Center, University of Arizona) on use of wastewater; and Sari Huuhtanen (Global Dry Toilet Association, Finland) on ecological sanitation.

BOX 12.3 EUROPEAN UNION'S URBAN WASTEWATER TREATMENT DIRECTIVE

The UWWTD (EU, 1991), complemented by the EU's other pollution control and environmental protection instruments, is a major legal tool that has contributed to the progress visualized in Figure 12.1.

The UWWTD, adopted in 1991, addresses the collection, discharge and treatment of urban wastewater. Its main objective is the protection of surface waters from the adverse effects of wastewater discharges. This is achieved through the requirement for collection and treatment of wastewater in all settlements (agglomerations) with a population equivalent, or p.e.,[10] larger than 2,000. The UWWTD provides for the biological treatment of wastewater (secondary treatment) in agglomerations larger than 10,000 p.e. or even smaller. In catchments with particularly sensitive waters (covering nearly 75% of the territory of the EU), such as those suffering from eutrophication, tertiary wastewater treatment can be required. The UWWTD laid out a gradual implementation schedule which requires systems in the largest agglomerations (and with potentially the largest impact) to be made compliant first.

Based on datasets submitted by 28 EU Member States, covering more than 19,000 agglomerations above 2,000 p.e. and generating a pollution corresponding to 495 million p.e., the European Commission assessed the overall compliance rate at 88%. An additional EUR 22 billion investment is forecasted, which will allow EU Member States to fully implement the UWWTD. In addition to investment, one of the main challenges to implementation is long-term planning (EC, 2016b). Where implementation of the UWWTD is well-advanced and combined sewerage systems are used, stormwater overflow can become more significant as a source of diffuse pollution. Therefore, reducing such overflow appears essential for improving compliance rates (Milieu, 2016). While compliance is a challenge, especially for the recently acceded countries, it is also an opportunity for improvement (Michaud et al., 2015).

Contributed by EEA.

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[10] Population equivalent, or p.e., is the unit used to quantify the pollution load under UWWTD. One p.e. corresponds to the organic load which has a five-day biochemical oxygen demand (BOD5) of 60 g of oxygen per day (Umweltbundesamt GmbH, 2015).

BOX 12.4 NATIONAL TARGET-SETTING UNDER UNECE-WHO/EUROPE PROTOCOL ON WATER AND HEALTH: ADDRESSING WASTEWATER CHALLENGES

The Protocol on Water and Health to the UNECE Water Convention is a legally binding instrument that requires Parties to set national and local targets covering the entire water cycle, including sanitation. The aim is to protect human health and well-being through improved water management, including the protection of water ecosystems, and by preventing, controlling and reducing water-related diseases. The Protocol's forthcoming programme of work for 2017–2019 sets an objective to strengthen countries' capacities and scaling up risk-based management approaches in water supply and sanitation. The Protocol's cross-sectoral planning and accountability approach offers a practical framework to translate into specific national targets in order to achieve the ambitions of SDG 6, including notably target 6.3 to halve the proportion of untreated wastewater and to substantially increase water recycling and safe reuse.

Sources: UNECE/WHO (2016).

Contributed by Nataliya Nikiforova (UNECE) and Oliver Schmoll (WHO Regional Office for Europe)

CHAPTER 13

UNECLAC | Andrei Jouravlev

With contributions from: Caridad Canales (UNESCAP); Eduardo Antonio Ríos-Villamizar, Emilio Lentini, Gustavo Ferro, Ivanildo Hespanhol, Jaime Llosa, Julio Sueros and Miguel Doria (UNESCO Montevideo Office); and Miguel Solanes and Shreya Kumra (UNECLAC)

LATIN AMERICA AND THE CARIBBEAN

Indigenous leader inspects a contaminated river in the Amazon rainforest

This chapter describes the challenges related to the recent expansion of wastewater management in the rapidly growing cities of the Latin America and the Caribbean region, highlighting the benefits of urban wastewater treatment and lessons learned in the process

Latin America and the Caribbean is largely a humid region with abundant water resources, although it contains some very arid areas. Agriculture is the largest user of water, accounting for over 70% of withdrawals, while domestic supplies and industry represent 17% and 13%, respectively (AQUASTAT, 2016). The region is highly dependent on hydropower, which provides over 60% of the electricity in the region, and it still has significant (74%) undeveloped technical potential (IEA, 2014). With 80% of the population living in urban areas, it is one of the most urbanized regions in the world, and is expected to urbanize even further, with 86% of its population residing in cities by 2050 (UNDESA, 2014). At present, there are four megacities in the region, with more than 10 million inhabitants each, and two more are expected to be added to this list by 2030.

13.1 The urban wastewater challenge

In the region, urban wastewater discharges are increasing due to: i) population growth (urban population has risen from 314 million in 1990 to nearly 496 million today, and is projected to reach 674 million in 2050) (UNDESA, 2014); and ii) expansion of water supply and sanitation services. In 2015, 88% of the urban population had access to improved sanitation facilities (UNICEF/WHO, 2015), of which probably less than 60% were connected to sewerage systems (UNICEF/WHO, 2000). Given that there was no parallel expansion of wastewater treatment in most of the region, urban sewage is a key concern for governments.

The population not connected to sewerage systems relies mostly on on-site disposal systems such as latrines and septic tanks. In these systems, wastewater is removed by direct runoff or percolation into the nearby watercourses and aquifers, often resulting in water pollution. On the whole, urban sewerage systems represent a larger challenge, because piped collection and interception concentrate the sewage in a limited number of disposal points (Idelovitch and Ringskog, 1997). Groundwater pollution is a common concern in the case of on-site disposal systems, which are still common even in large cities.

For many decades, the coverage of sewage treatment had remained very low (PAHO, 1990). The main reasons for this situation were the need to prioritize the expansion of water supply and sanitation services, as well as the restrictions posed by the high cost of wastewater treatment. This was especially challenging within the context of limited government budgets, water tariffs that did not cover the cost of service provision, lax enforcement of existing regulations, high levels of poverty and inequality, and the need to address other urgent social needs.

As a result, nearly all urban wastewater, including all but the most toxic industrial wastes, was discharged into the nearest water bodies without any treatment. Many rivers, lakes and coastal waters, particularly those located downstream of large cities, were, and still are, heavily contaminated. This has serious consequences not only for the environment, but also for the health and well-being of the population and the overall socio-economic development of the region, especially in the case of the agriculture and tourism industries (see Box 13.1).

A critical and widespread problem is the use of contaminated water – mostly river water with unacceptable levels of pollution, but also raw sewage, and in a few cases, treated wastewater – for irrigation near large cities (i.e. peri-urban agriculture), particularly in arid and semi-arid areas. This

BOX 13.1 **CONSEQUENCES OF THE DISCHARGE OF UNTREATED URBAN WASTEWATER: THE 1991 CHOLERA EPIDEMIC**

The cholera epidemic of 1991 was one of the most severe ever in Peru, with a total of almost 323,000 cases and 2,900 deaths recorded that year. Besides Peru, many other countries were also affected, with a total of 391,000 cases and 4,000 deaths in the region.

The loss of income from tourism and the restrictions imposed on food products resulted in substantial economic losses for the affected countries. In Peru alone, the losses in fish product exports exceeded US$700 million. The epidemic also brought about a process of restructuring in view of the more stringent sanitary requirements of importing countries and the increase in exporters' costs.

This incident caused many countries to give high priority to the water supply and sanitation sector. Particularly, the need to protect access to external markets was one of the factors that motivated the Government of Chile to initiate an ambitious investment programme, which culminated in universal urban wastewater treatment.

Source: Jouravlev (2004).

is mostly practiced by small-scale farmers, who cultivate fruits and vegetables for local markets. The main motivation for wastewater irrigation is the intense competition for water in river basins where large cities are located. The fact that urban wastewater constitutes a reliable, low-cost and nutrient-rich source of water provided an additional impetus. The downside, however, is that sanitary norms are seldom respected, partly because monitoring and control systems are weak, and in some cases, inexistent. Nevertheless, there are instances of successful reuse of treated urban wastewater for irrigation, for example in Argentina, Bolivia, Chile, Mexico and Peru.

13.2 Recent expansion of urban wastewater treatment

The situation has begun to change over the last two decades, with increasing attention being paid not only to water supply and sanitation services, but also to developing wastewater treatment facilities. The reasons for this change are: i) the high levels of water and sanitation coverage achieved as part of the MDGs process (UNICEF/WHO, 2015); ii) the improved financial situation of many service providers, particularly in larger cities, which in recent years have made important advances towards cost recovery (Ferro and Lentini, 2013); and iii) the strong socioeconomic growth in the region in the first decade of this century, which lifted an important number of people out of poverty and led to the emergence of a middle class. A further contributing factor was the integration of regional economies into global markets. Expansion of wastewater treatment is very important in this respect, since public health and environmental problems related to water pollution can result in the loss of many years of efforts to develop export markets (see Box 1) (Jouravlev, 2004).

In some cases, important wastewater management programmes were also initiated as a result of public protests and court decisions. The most emblematic example is the case of the Matanza-Riachuelo River Basin in Argentina, where the authorities – through a public interest litigation process – were sentenced to clean the river, after which they initiated a comprehensive plan for the environmental recovery of the river basin (Rossi, 2009).

The coverage of urban wastewater treatment has almost doubled since the late 1990s and is now estimated to have reached between 20% (Sato et al., 2013) and 30% (Ballestero et al., 2015) of the wastewater collected in urban sewerage systems. The principal technologies used (approximately 80% both in terms of the number of facilities and of treated flow) are stabilization ponds, activated sludge and up-flow anaerobic sludge blanket reactors (Noyola et al., 2012).

13.3 Ongoing concerns and expanding opportunities

On the whole, the region has seen mostly isolated wastewater treatment projects that are a response to local social and environmental problems, instead of nation-wide sustained integrated programmes. Moreover, many wastewater treatments plants, particularly in smaller communities, are plagued by poor operation and maintenance, and are sometimes eventually abandoned because of a lack of technical and financial capacity among local governments and service providers. Most of these facilities are small and cannot take advantage of economies of scale, resulting in high costs and high probability of incompliance with discharge standards (Noyola et al., 2012). Urban wastewater is still largely regarded as waste and as leading to additional costs, rather than a potential source of water supply and nutrients which can substantially reduce the pressures on the environment.

Of all countries in the region, Chile has advanced the most in this respect, enjoying universal urban wastewater treatment (SISS, 2015). A few other countries in the region have made substantial progress in the expansion of wastewater treatment. Countries that treat more than a half of their urban sewage include Brazil, Mexico and Uruguay (Lentini, 2015). There are ambitious plans for the expansion of wastewater treatment in many large cities, such as Buenos Aires, Bogotá, Lima, Mexico City and São Paulo (Ballestero et al., 2015), but most of these plans have been delayed for years due to financial and institutional limitations. Treated wastewater could be an important source of water supply in some of these cities, particularly those located in arid areas (Lima, for example) or where long-distance transfers are required to meet growing demands (as is the case in São Paulo).

The expansion of urban wastewater treatment requires significant investments, which until recently, most countries could not afford. Latin America and the Caribbean would need to invest more than US$33 billion to increase the coverage of wastewater treatment to 64% by 2030 (Mejía et al., 2012). According to another estimate, about US$30 billion is needed to halve the percentage of wastewater that currently does not receive treatment (Lentini, 2015). In addition, approximately US$34 billion is required for the expansion of stormwater drainage systems (Mejía et al., 2012), which would reduce pollution resulting from uncontrolled urban runoff. This is an important aspect of urban wastewater management that also has significant social and economic implications: since much of the region lies in tropical and subtropical zones characterized by heavy rainfall, and most cities lack adequate stormwater drainage infrastructure, urban flooding is a common and costly phenomenon which affects a large part of the population.

> There are four megacities in the region, with more than 10 million inhabitants each, and two more are expected to be added to this list by 2030

13.4 Benefits of urban wastewater treatment

Investments in urban wastewater treatment are justified not only in terms of health and environmental benefits, but also due to their positive impacts on socio-economic development. For example, in Chile, the expansion of wastewater treatment led to the following benefits: i) clean water for thousands of hectares of irrigated land and production of high-value crops; ii) promotion of the tourism industry and water-based recreation; iii) reduced risk of agricultural exports being lowered due to possible complaints about wastewater irrigation; iv) increased competitiveness of high-quality pollution-free domestic products in external markets; v) increased employment associated with exports and tourism industries; and vi) better quality of water bodies used as sources for water supply (SISS, 2003). Furthermore, the expansion of urban wastewater treatment has also made it possible to: vii) capture methane

Latin America and the Caribbean would need to invest more than US$33 billion to increase the coverage of wastewater treatment to 64% by 2030

and utilize it for power generation and domestic gas supply, thus reducing GHG emissions; and viii) use wastewater not only for irrigation, but also for industrial and other uses.

13.5 Other sources of wastewater

As urban wastewater treatment has expanded, other environmental issues have begun to emerge, including sewage sludge treatment (Rojas Ortuste, 2014), and agricultural non-point source pollution – the leading source of water quality degradation in many river basins and aquifers. As regional exports of agricultural commodities have increased, so has the contamination caused by seepage and runoff of agricultural wastewater containing fertilizers, pesticides and other agrochemicals, which are frequently used with little or no control. Significant water pollution caused by irrigation has been reported, for example, in the Dominican Republic, Mexico, Nicaragua, Panama, Peru and Venezuela (Zarate et al., 2014). This contamination is of particular concern in the case of groundwater, which is an important source of supply both for domestic water services and irrigation.

13.6 Lessons learned

The main lessons from the regional experience in wastewater management are the following:

- the design of any wastewater management programme should take the structural limitations of national economies into account, critically consider all available options (technologies, sources of financing, property structure, incentives, etc.), and be structured and sequenced in such a way that it does not become a burden on the economy and on citizens;
- government priorities, as seen in budgetary allocations and the establishment of effective institutions, and political non-interference in technical decision-making are critical, and so is the pursuit of efficiency (careful consideration of the costs and benefits, effective implementation, enforcement and control, reduction of transaction costs, control of capture and corruption, good information, taking advantage of economies of scale and scope, etc.); and
- to reap all the benefits of wastewater management and to avoid excessive costs, it is essential to give preference to integrated plans at the river basin level that incorporate both wastewater treatment and reuse, rather than project-by-project approaches limited to a single sector.

PART IV

RESPONSE OPTIONS

CHAPTER 14

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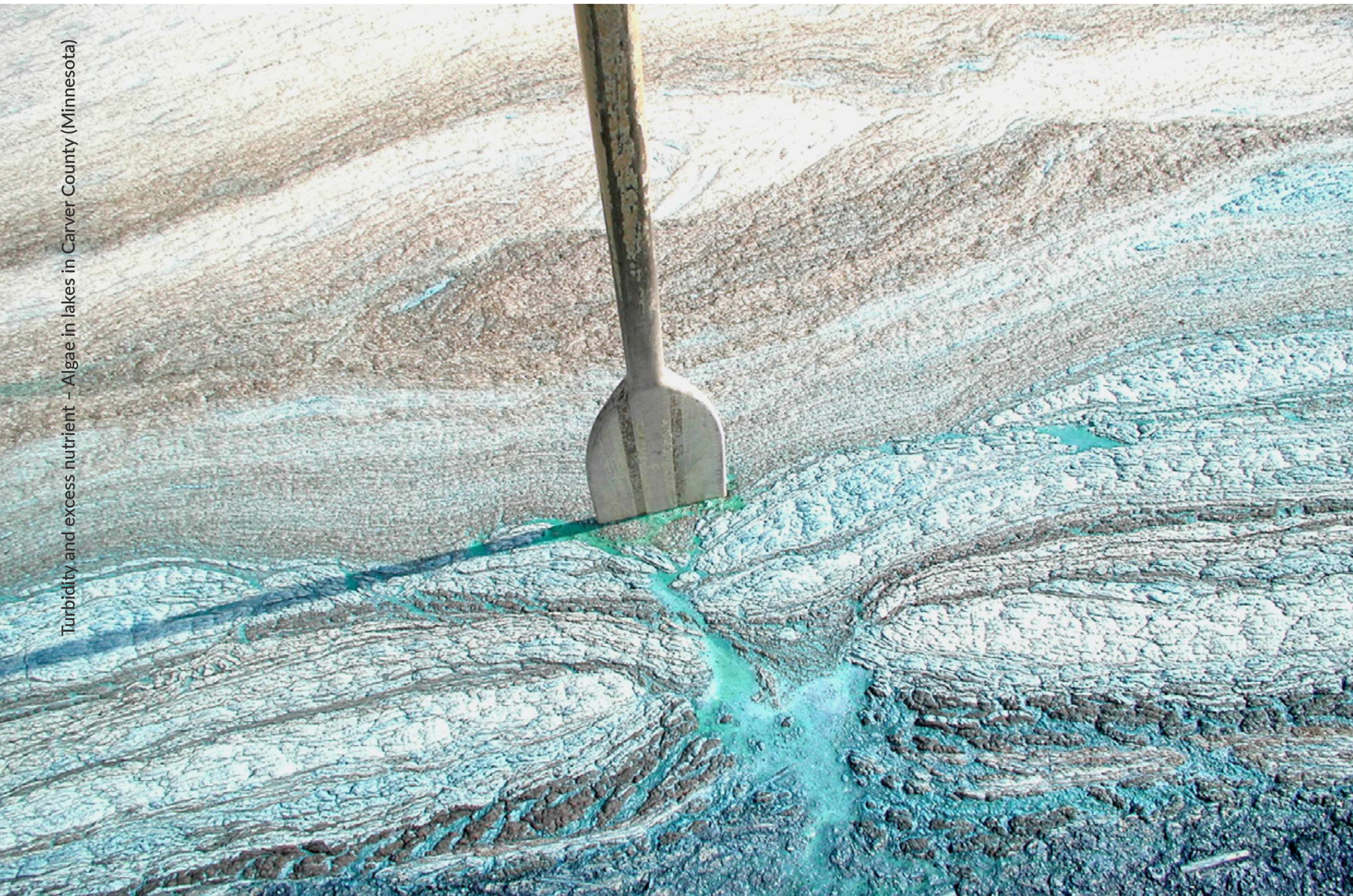
PREVENTING AND REDUCING WASTEWATER GENERATION AND POLLUTION LOADS AT THE SOURCE



Turbidity and excess nutrient - Algae in lakes in Carver County (Minnesota)

This chapter describes various institutional, technical and financial mechanisms for controlling and preventing the discharge of pollutants into wastewater streams and reducing wastewater volumes.

The Kashmiri proverb stating that "it is easy to throw anything into the river, but difficult to take it out again" summarizes the importance of pollution prevention measures. Indeed, remedial actions to clean up polluted sites and water bodies are generally much more expensive than measures to prevent pollution from occurring.

Thus, approaches to water pollution control which focus on wastewater prevention and minimization – through the reduction of water consumption, in-plant refinement of raw materials and production processes, and recycling of waste products, for example – should be given priority over traditional end-of-pipe treatment whenever possible. More broadly, sustainable water management looks towards decoupling water consumption and pollution from economic development (UNEP, 2015c). In order to avoid merely shifting problems between life cycle stages or environmental compartments, it is also important to consider how water is used and polluted across entire production and consumption systems, rather than focusing only on a specific stage such as wastewater treatment and ending up, for example, removing pollution from wastewater while increasing air pollution (UNEP, 2012a).

In order for this to happen, an enabling environment needs to be in place with supportive policies that are actively implemented, including the enforcement of regulations and penalties, clean and efficient technologies, and innovative financial mechanisms (see Box 14.1).

14.1 Mechanisms for controlling and monitoring pollution

Trade and market conditions can have significant and far-reaching implications for wastewater generation and pollution from productive activities. For instance, 19% of the global water footprint is not for domestic consumption but for export (Mekonnen and Hoekstra, 2011). Quantitative, science-based approaches such as Life Cycle Assessments (LCA) are relevant in this sense, in order to avoid policies that favour the 'exportation' of the most polluting industries in an attempt to reduce wastewater-related problems domestically (UNEP, 2012b).

Of special interest are the certification requirements for organic products, as less pesticide application leads to a reduction in the chemical pollution of wastewater. Other labelling systems, such as ISO 14024 type 1 ecolabels[11] (e.g. European Ecolabel, Nordic Swan or Blue Angel of Germany), often include wastewater criteria for relevant products, as they tend to cover key impacts along the product life cycle. Being of voluntary nature, these product information systems constitute an incentive for companies to increase their competitiveness, given the current market trends to support chemical-free production, recycled packages and other environmentally sound practices. However, most of the traded products are not certified and thus the impacts of these voluntary approaches are limited.

Monitoring and reporting of both pollutant discharges to the environment and ambient water quality are also of critical importance for achieving progress. If something is not measured, the problem cannot be defined and the effectiveness of policies cannot be assessed. With the adoption of the 2030 Agenda for Sustainable Development (see Chapter 2) and the initiation of the Global Enhanced Monitoring Initiative (GEMI) under the UN-Water framework, periodic monitoring of ambient water quality and wastewater treatment are expected to guide national reporting mechanisms and eventually allow for global comparisons.

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[11] Global Ecolabelling Network, an association of national labelling schemes from around 25 countries (GEN, n.d.).

The creation of Pollutant Release and Transfer Registries (PRTR) provides some helpful experience that could potentially be applied to monitoring wastewater. Originally established as part of the EU's Directives, the North American Free Trade Agreement (NAFTA) and the OECD rules, national PRTRs are now being used by 33 countries around the world to record chemical emissions into air, water and soil from industrial facilities (EEA, n.d.). Although PRTRs do not include information on wastewater treatment, they clearly identify sources of pollution, which supports investment decisions on the upgrade and construction of treatment facilities. Other monitoring efforts include environmental impact assessments, cost-benefit analyses of wastewater production and reuse, and sanitary controls. However, their application is generally limited to project and company levels.

A series of options can be considered by decision-makers in the public and private sector to address wastewater prevention, generation, monitoring and reuse. The industrial sector applies several different methods of water recycling to reduce its production and withdrawal costs, comply with effluent and environmental regulations, and potentially even generate revenue. Some industries have gone a step further by adopting the zero liquid discharge (ZLD), as in the case of the textile industries in Tirupur, India (see Box 14.2). Additionally, industry-led sustainability initiatives tend to address wastewater/pollution issues with more comprehensive approaches, by devising standards and guidelines to assess environmental and social sustainability from a life cycle system point of view (see Section 6.4).

The new SDGs, particularly SDG 6 Target 6.3 on water quality and wastewater, and SDG 12 on responsible consumption and production, will foster policy formulation and action to implement the measures needed. As a result, national-level pollution prevention and wastewater management should benefit from international cooperation and technology transfer mechanisms, capacity-building schemes and other means of implementation.

BOX 14.1 GUIDING PRINCIPLES FOR PREVENTING AND REDUCING WASTEWATER GENERATION

1. Prevent pollution rather than treating symptoms of pollution. Prioritizing water pollution control and addressing the causes of water pollution by identifying hazardous substances that need to be prohibited or strictly regulated (e.g. creating 'Red Lists') and providing instruction and guidance to users.
2. Use the precautionary principle. Actions to avoid potential environmental damage by hazardous substances should not be postponed on the grounds that there is no conclusive scientific evidence.
3. Apply the polluter pays principle, where the costs of pollution prevention, control and reduction measures are borne by the polluter. Such an economic instrument aims to encourage and induce behaviour that puts less strain on the environment.
4. Apply realistic standards and regulations. Unrealistic standards and non-enforceable regulations may do more harm than having no standards and regulations at all, because they create an attitude of indifference towards rules and regulations, both among polluters and administrators.
5. Balance economic and regulatory instruments. The regulatory approach to water pollution offers control to authorities over what environmental goals can be achieved and when they can be achieved (Bartone et al., 1994). Its major disadvantage is its economic inefficiency. Economic instruments provide incentives to polluters to modify their behaviour in support of pollution control whilst providing revenue to finance pollution control activities.
6. Apply water pollution control at the lowest appropriate level. The appropriate level may be defined as the level at which the most significant impacts are experienced.
7. Establish mechanisms for cross-sectoral integration. In order to ensure the coordination of water pollution control efforts within water-related sectors, formal mechanisms and means of cooperation and information exchange need to be established.
8. Encourage a participatory approach involving all relevant stakeholders. The participatory approach involves raising awareness of the importance of water pollution control among policy-makers and the general public.
9. Provide open access to information on water pollution. A precondition for participation is free access to information held by public authorities.
10. Promote international cooperation on water pollution control. Transboundary water pollution, typically encountered in large rivers, requires international cooperation and coordination of efforts in order to be effective.

Further, the application of integrated water resources management (IWRM) principles and best practices in subsector projects and programmes, while promoting bottom-up multiple stakeholder management, will go a long way towards pollution control while improving water and wastewater management.

Source: Adapted from Helmer and Hespanhol (1997, pp. 17-20).

14.2 Technical responses

14.2.1 Resource-efficient and cleaner production

The resource-efficient and cleaner production (RECP) methodology presents a comprehensive approach in terms of coverage of issues and a continuous application of preventive environmental strategies to products, processes, and services. It aims to promote production efficiency through better use of materials, energy and water, through sound environmental management, and by minimizing waste and emissions, thus creating a safer environment with fewer risks to people and communities. It is based on life cycle thinking, applied along product value chains (for both goods and services) to identify key issues (including wastewater), and proposes a number of practical solutions through resource recovery and recycling, adoption of closed-cycle manufacturing and extension of the lifespan of manufactured goods, among others (UNEP, n.d.; RECPnet, n.d.a.).

One particular tool to mention is the promotion of resource efficiency in small- and medium-sized enterprises (PRE-SME).[12] It is designed for SMEs as they dominate sectors like textile, dry cleaning, metal finishing, printing, food and beverage, and some subsectors of electronics, all of which have high water-use rates and associated environmental and social impacts. SMEs also face greater challenges increasing their resource efficiency and cleaning their production approaches in operations, due to a lack of awareness and technical and financial capacities (see Chapter 6). Box 14.3 provides practical examples of RECP application with SMEs in Tanzania.

14.2.2 Environmentally-sound technology for domestic wastewater separation and treatment

Chapter 34 of Agenda 21 defined environmentally sound technologies (ESTs) as technologies that are better than those for which they are substitutes in terms of protecting the environment, reducing pollution, sustainably using resources, promoting the recycling of wastes and products, and most importantly safely handling residual wastes (UNCED, 1992, item 34.1). In this regard, on-site wastewater treatment systems, focusing on ZLD and separation of waste streams at the source, can be qualified as ESTs. However, the conduction of an LCA study to compare the environmental (and social and economic)

> **In order to decrease water consumption and control the release of contaminants and by-products, participatory approaches, better communication, awareness raising and education are indispensable**

BOX 14.2 ZERO LIQUID DISCHARGE IN TEXTILE INDUSTRIES IN TIRUPUR, INDIA

The dyeing and bleaching industry in the South Indian knitwear hub Tirupur is known as the first to opt for zero liquid discharge (ZLD) in a systematic manner, eliminating the release of pollutants. The components of ZLD, including reverse osmosis, enable extensive reuse and recovery of water and salts, and the process minimizes the freshwater requirements.

The dyers in Tirupur were trucking in freshwater from elsewhere to safeguard production quality, until a public-private water supply scheme was set up, partly based on a loan from the United States Agency for International Development (USAID). As the water is relatively costly, reuse makes sound commercial sense, but this has to be weighed against the high energy and operational costs of the ZLD enabling machinery.

In the mid-1980s, there was no enforcement of effluent standards. The transformation was prompted by many actors. The region's farmers stood behind the initial push, along with the Pollution Control Board and the court system. However, the pressure to change behaviour at a large scale came from the High Court in incremental steps: after it ordered closure of all dyeing factories in 2011, the government offered an INR 2 billion (roughly US$30 million) interest-free loan to ensure more functional treatment.

Whereas full compliance may not be achieved in the short to medium term, a new ZLD production regime has been instituted in Tirupur.

Source: Grönwall and Jonsson (forthcoming).

Contributed by Jenny Grönwall (SIWI).

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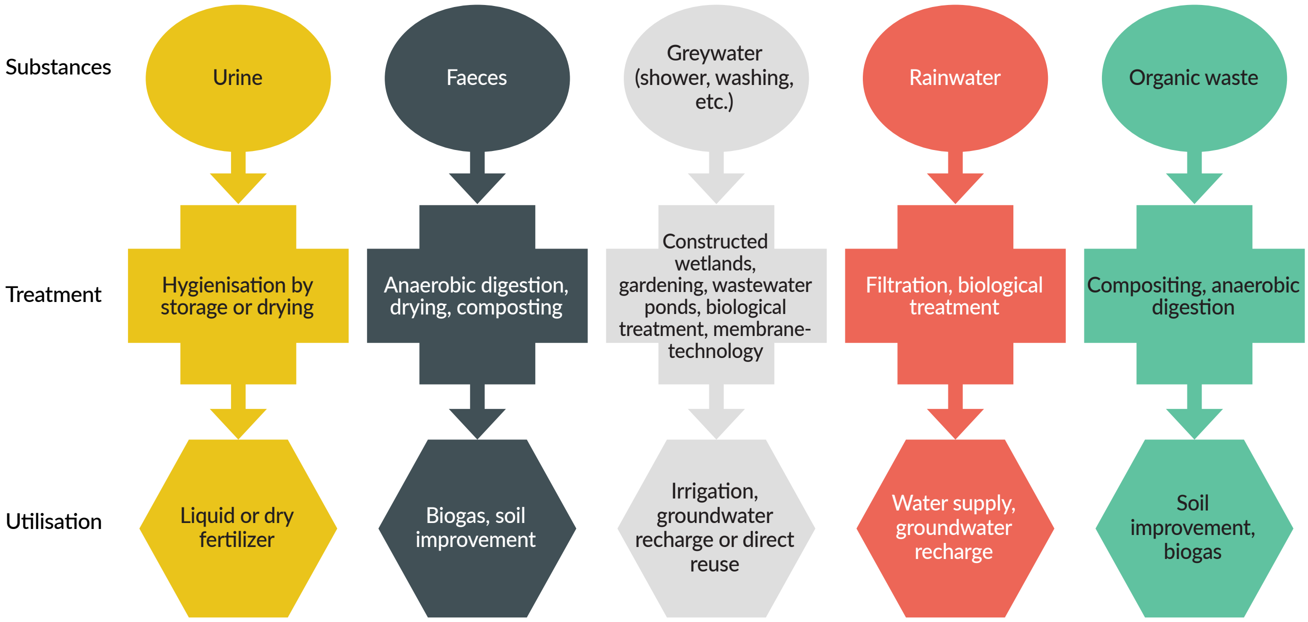
[12] For further information, see www.unep.org/resourceefficiency/Business/CleanerSaferProduction/ResourceEfficientCleanerProduction/Activities/PromotingResourceEfficiencyinSMEsPRE-SME/Resources/ResourceKit/tabid/105557/Default.aspx.

Figure 14.1 Waste segregation and possible utilization options



Source: UNESCO-IHP/GTZ (2006, Fig. 4, p. 15).

BOX 14.3 EXAMPLES OF RESOURCE-EFFICIENT AND CLEANER PRODUCTION FROM TANZANIA

The examples of two SMEs in Tanzania demonstrate the benefit of preventive approaches such as RECP, both from the environmental impact point of view, including wastewater, and considering the associated economic benefits to the companies.

Musoma Textile Mills Tanzania Limited (MUTEX) received training on RECP to improve its resource efficiency and environmental performance. Some notable benefits achieved include resource recovery (caustic soda); enhanced energy and water efficiency; reduction of emissions, solid waste and wastewater; and improved occupational health and safety conditions. The entire RECP programme saved more than US$293,322 per year.

Tanzania Breweries Limited Mwanza plant started RECP implementation with the objective of reducing water and energy usage, waste generation and operational costs, while improving global sustainability compliance as well as its business image. The execution of RECP at the breweries led to annual savings of US$37,500 in water bills and US$56,250 in energy consumption, reduction of CO_2 emissions by 50%, reduction of solid waste generation by 39% and of wastewater generation by 42%.

Source: RECPnet (n.d.b.) and CPCT (n.d.).

BOX 14.4 THE CARIBBEAN REGIONAL FUND FOR WASTEWATER MANAGEMENT (CReW)

Within the Wider Caribbean Region, it is often a tremendous challenge to secure funding for sectors such as education, health, drinking water supply and wastewater management, with the latter consistently receiving the least investment. However, without adequate levels of investment, the consequence will be a continuing discharge of untreated wastewater, which threatens the Region's economic development and the quality of life of its people. The CReW, funded by the GEF and implemented by the Inter-American Development Bank (IDB) and UNEP, offers one way of addressing the issue of insufficient funding for wastewater infrastructure in the region.

CReW has tested two types of funding mechanisms: revolving funds (in Belize, Trinidad and Tobago, and Guyana) and a credit enhancement facility (CEF) in Jamaica. The CEF was established with a reserve guarantee of US$3 million provided by CReW, as leverage financing for a further US$9 million to fund wastewater projects. The K-factor wastewater utility surcharge, established in 2008, is used to repay funds to the CEF. This innovative model creates an incentive for allocating the resources garnered from the monthly collection of the K-factor funds (a portion of the water tariff) for debt servicing for larger commercial bank loans, rather than using the funds directly for capital investments in the sector. Belize, Guyana and Trinidad and Tobago use CReW resources (US$5 million, US$3 million, and US$2 million respectively) to create revolving funds which provide loans to the respective water utilities to finance selected wastewater projects. Replenishment of these revolving funds depends on income generated primarily by the interest from the loans and through the tariff regime. The case of Guyana is special, as the allocation targets primarily the private sector.

Among the lessons learned are the notion that the sustainability of financing for the wastewater sector depends predominantly on the commitment of governments; the adequacy of national policies, laws and regulations; the level of enforcement of existing laws and regulations; and the presence of sufficient, ongoing funding for upgrading, operating and maintenance. The project helped increase awareness of: i) the issue of poor wastewater management amongst decision-makers; ii) the importance of integrated water and wastewater management; iii) innovative ways of approaching financing for wastewater management; and iv) a better understanding of the requirements for sustainable funding in the sector.

Source: CReW (n.d.) and Daniels (2015).

> **Separating wastes at the source can be easier and more cost-effective than trying to segregate them once all have been mixed up**

performance of specific technologies in different geographical conditions is recommended in order to determine the best ESTs in different settings.

Large efforts have been invested in research and development on source separation over the last 20 years, covering low- and high-tech solutions in rural and urban contexts at different scales (Andersson et al., 2016). Separating wastes at the source can be easier and more cost-effective than trying to segregate them once all have been mixed up.

For instance, decentralized wastewater treatment systems (DEWATS) and ecological sanitation (EcoSan) are highlighted as promising options to balance socio-economic development and the provision of basic services for less privileged communities. These treatment systems dispense with the need for sophisticated technical control and maintenance, and high inputs of energy and water. They also enable the recovery of nutrients for agriculture, thus preserving soil fertility, assuring food security, minimizing water pollution and the use of synthetic fertilizers, and sometimes recovering bio-energy (see Section 15.4).

EcoSan considers human excreta, organic wastes and wastewater as resources, with high potential for water reuse and component recycling. They are mainly 'dry sanitation'. The main advantage of urine-diverting dry toilets, an example of EcoSan, in contrast to conventional pit latrines, is the separation of urine and faeces and the conversion of faeces into a safe, dry and odourless material (see Figure 14.1). The risk of ground and surface water pollution is minimized through the safe containment of faeces and urine.

14.3 Financial approaches and behavioural change

Referring to Box 14.1 on the guiding principles, it is worth remembering that many multilateral environmental agreements (MEA) bear economic incentives for preventing and reducing wastewater generation, which can include the precautionary principle, the polluter pays principle, public-private partnerships and innovative tariff policies. Success stories of the use of innovative financial mechanisms from the Caribbean and the USA are illustrated in Boxes 14.4 and 14.5.

A paradigm shift in behavioural change is of paramount importance to reverse the current trend of wastewater generation. In order to decrease water consumption and control the release of contaminants and by-products, participatory approaches, better communication, awareness raising and education are indispensable.

> **Trade and market conditions can have significant and far-reaching implications for wastewater generation and pollution from productive activities**

BOX 14.5 STATE REVOLVING FUND (SRF) FOR WASTEWATER INFRASTRUCTURE FINANCING

In the USA, the State Revolving Fund is one of the sustainable financing programmes that provide financial savings for water projects that benefit the environment, including protection of public health and conservation of local watersheds. National and state contributions fund loans for a wide variety of water quality projects, including all types of runoff, watershed protection or restoration and estuary management projects, as well as more traditional municipal wastewater treatment projects, including water reuse and conservation projects.

It allows states to provide funding for their highest-priority water quality projects using a scoring approach to project evaluation. Funds to establish or capitalize the Clean Water State Revolving Fund (CWSRF) programmes are provided through national government grants via the US EPA and state matching funds that are equal to 20% of national government grants. CWSRF monies are loaned to communities below market interest rates, and loan repayments are recycled back into the programme in order to fund additional water quality protection projects. The revolving nature of these programmes provides for an ongoing funding source that will last far into the future.

The wastewater treatment plant in Escambia County, Florida (USA), destroyed by Hurricane Ivan, and replaced and relocated away from the coastal plain and built to be more resilient. The plant now reuses 100% of its water.

Source: US EPA (n.d.c.)

Contributed by Sasha Koo-Oshima (US EPA).

CHAPTER 15

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With contributions from: Xavier Leflaive (OECD Environment Directorate)

ENHANCING WASTEWATER COLLECTION AND TREATMENT

Sludge digestion installation in a wastewater plant, which produces methane and supplies energy

This chapter examines a number of options and responses for enhancing wastewater collection and treatment, with a special emphasis on the advantages of low-cost decentralized systems.

15.1 Sewers and waterborne sanitation

The importance of sewerage as a means of transporting waste materials away from human sources and other economic activities is well-documented, as are its impacts. Despite more ecologically acceptable alternatives, waterborne waste disposal remains the prevalent method for sanitation and for evacuating wastewater from domestic, commercial and industrial sources. Other sanitation options, such as on-site systems, are perfectly suited to rural areas and low population density settings, but are expensive and nearly impossible to manage in dense urban environments, aside from the most developed economies. In many cases, significant challenges still exist in the collection and transport of faecal sludge from on-site facilities. According to a recent study in the city of Kampala (IWMI, 2012), more than 80% of the users of such facilities had no experience with emptying personal latrines and over 60% of the collected septage came from institutional and commercial sources (see Figure 4.4).

The number of households connected to sewer systems correlates (to a greater or lesser extent) with the connections to a water supply, although always in much lower proportions. Recent reports (UNICEF/WHO, 2015) clearly show that, globally, the proportion of people connected to a sewer system (60%) is higher than had been previously assumed. Even in rural areas where the number of connections is typically low, there is a significant share of people with a connection to a sewer system (16%). This contradicts previously published estimates which quoted 10% or less (Corcoran et al., 2010) (see Figure 5.1).

Many large cities in developed and transitioning economies have extensive sewerage systems, some of which are still functioning effectively some 100 years after construction. London still relies on trunk sewers constructed in the Victorian era as part of the reticulation used today. Complications arise with increasing urbanization and excessive connections to sewer systems that surpass their original design capacity. Ageing wastewater collection systems generate a number of problems, including corroded concrete, cracked tile, collapse and clogging. Addressing these problems can be expensive. US EPA (2016) has estimated that combined sewer overflows (CSOs) correction, the rehabilitation and replacement of existing conveyance systems, and the installation of new sewer collection systems account for 52% of the US$271 billion in investments needed to meet the country's wastewater infrastructure needs.

15.2 Low-cost sewerage

Driven by the high costs of conventional sewerage, methods of low-cost sewerage were conceived in response to the challenges faced by most developing countries: low tariffs combined with insufficient governmental budgets, high poverty and expensive infrastructure. These low-cost systems come in many different types, but they normally use piped networks with a smaller diameter, laid at shallower gradients and at shallower depths underground. The design principles differ from those used in conventional sewer design and also focus on the concept that solid-free sewage is conveyed in the system, with interceptor boxes (similar to small septic tanks) collecting raw wastewater from a household or group of households. These systems lend themselves to community management and are also very well-suited to extend and expand existing systems. One drawback is that they are not suitable for stormwater drainage.

The concept was first pioneered in Brazil by Carlos Melo (2005). Low-cost sewerage systems have become a method of choice for neighbourhoods of all income levels, as they have all the characteristics required to be the *de facto* standard for all sewerage. However, conservatism amongst public health authorities and sanitary engineers has resulted in only sporadic uptake worldwide. Australia has adopted a low-cost approach in some parts of the country (Palmer et al., 1999) and low-cost systems are likely to gain in popularity. The systems can also be used to connect satellite communities to centralized systems, and have been used in refugee settings (Van de Helm et al., 2015) (see Section 10.2.1). Mara and Alabaster (2008) make a case for networked systems at the neighbourhood level as a cost-effective way to provide services to smaller secondary urban centres. At this point, there are not yet many examples of the technology being evaluated, but the cost data, particularly from countries like Brazil, clearly show that it can be financially sustainable. In Brazil, the cost of simplified sewerage (a type of low-cost sewerage) per person has been shown to be twice lower than the cost of conventional sewerage (i.e. US$170 vs US$390) (Mara, 1996).

15.3 Combined sewerage

One important issue in relation to wastewater collection is its source. In old systems, like the one used in Paris, the original sewers (from 1852) were designed only for rainwater and grey water; a later decree from 1894 imposed the house owners to put all kinds of wastewater, including blackwater, in the combined sewers (Bernhardt and Massard-Guilbaud, 2002; Tréhu, 1905). Although a variety of users connect to sewer networks, most systems were designed as so-called ‘combined systems’, in which stormwater and other types of urban runoff are discharged to the sewers. This was done, presumably, in order to limit the costs of purchasing large diameter drains, but it resulted in dilute sewage in periods of high rainfall. Although this may have been acceptable when population densities were low and the assimilative capacity of the receiving waters was adequate, recent development and city expansions have led to a complex and often hazardous combination of different chemical and biological substances. Combined sewerage should therefore generally not be considered an effective solution. In an effort to move away from combined systems, much work has been undertaken on sustainable urban drainage systems (SUDS) (Armitage et al., 2013).

Sewer systems are suitable for so-called ‘point sources’ of pollution, but the real challenge is how to collect diffuse or non-point pollution sources. Two major sources are the runoff from agricultural land that has received fertilizers, and the runoff from areas where intensive livestock is kept, as this often leads to drugs used for veterinary purposes being present in the water (see Chapter 7). Although many intensive agricultural facilities install collection and treatment systems (see Box 15.1), this is still not general practice due to the high costs associated and/or the lack of regulation or enforcement (FAO, 2005).

15.4 Decentralized treatment (DEWATS)

In addition to centralized wastewater treatment plants, decentralized systems have also shown an increasing trend. Many of the approaches to decentralized wastewater treatment systems (DEWATS), pioneered by organizations such as the Bremen Overseas Research and Development Association (BORDA) and the Consortium for DEWATS Dissemination Society, have found their rightful place as a part of sanitation systems for rapidly expanding urban areas and also for certain isolated communities where conventional sewerage is precluded on economic grounds. DEWATS and low-cost sewerage (see Section 15.2) are naturally complimentary. DEWATS can also serve as a medium-term solution pending the large-scale design of centralized systems, and there is significant flexibility on their use.

Indeed, large-scale centralized wastewater treatment systems may no longer be the most viable option for urban water management in many countries, due to high maintenance costs and resource needs. Moreover, they often require large areas of land and are too inflexible to meet the needs of rapidly expanding urban areas. This holds true for water supply and wastewater infrastructure, rainwater collection and drainage.

DEWATS serve individual or small groups of properties. They allow for the recovery of nutrients and energy, save freshwater and help secure access to water in times of scarcity (OECD, 2015b). They may require less up-front investment than larger, centrally piped infrastructures, and are more effective in coping with the need to scale up (or down) services to needs. However, they do require individuals with a minimal amount of training to take care of their operation and maintenance. Through decentralized technologies, sustainable neighbourhoods in cities could partly replace traditional public systems (OECD, 2013b). A challenge of DEWATS may be that local communities need to accept that they live close to the treatment facilities, so efforts must be made to make the plants aesthetically acceptable. For this reason, systems based on reed beds are often favoured.

15.5 Decentralized stormwater management

Decentralized stormwater drainage has a good potential for ‘source control’ technologies that handle stormwater near the point of generation. For instance, green roofs or pervious surfaces capture rainwater before it runs onto polluted pavements and streets. These solutions can alleviate peak flows, minimize the risks of urban floods and pollution, and reduce the need for investments in additional hard infrastructure and treatment facilities. They can attract private investments, encouraging property and land developers to invest in new buildings equipped with localized drainage systems. This may require changes in local by-laws, as local regulations will, to a great extent, dictate the final choice.

On the other hand, decentralized stormwater drainage only offers a solution for temporary retention, as the water will ultimately need to be transported to sewer systems. In some cases, the maintenance costs will be higher, but decentralized systems help to attain benefits like improved human well-being, absorption of air pollution and moisture retention, thus lowering ambient temperature and attenuating the urban heat island affect, ultimately contributing to the greening of cities. Decentralized systems can also be used for the treatment of runoff from highways.

Experience accumulates with the implementation and exploitation of decentralized sanitation and urban drainage. Nonetheless, some barriers have to be overcome, such as social perceptions and difficulties associated with retrofitting. However, the experience of Suwon City (see Box 15.2) suggests that this is feasible. Lack of policy coherence can pose additional barriers, for instance when water prices fail to reflect the opportunity cost of the use of the resource, or when land use and urban development do not take the risk of urban flooding into account. An additional challenge is the need to manage wastewater at different scales (from buildings to the municipal level, to even larger levels). These barriers can be overcome by a combination of information campaigns, a whole-of-government approach to urban water management (including policies, laws and regulation), business models for water utilities and land development that factor in externalities related to wastewater management, and a long-term vision of the challenges in the water sector and the opportunities for urban development.

15.6 Evolution of treatment technologies

Significant advances have been made in treatment technologies, since the original development of aerated systems (e.g. activated sludge and trickling filters) during the 1920s. The selection of treatment systems has been driven by the prevailing economic situation or by other factors like global warming, water scarcity, environmental quality issues and/or land use planning. In the rapidly urbanizing centres worldwide, the prevention of the discharging of carbonaceous material was the priority in order to protect receiving waters being starved of oxygen.

BOX 15.1 WASTEWATER COLLECTION AND RECYCLING FROM GREENHOUSES IN ETHIOPIA

Sher Ethiopia produces roses for export and employs around 10,000 local people. The flower production takes place in large greenhouses located next to Lake Ziway in the Ethiopian municipality of Ziway, which relies on the lake for drinking water and food (fishery). Water from the lake is also used for agricultural irrigation, including 500 hectares of roses.

Before the project was initiated, the various forms of wastewater from the greenhouses (stormwater runoff, water used for cleaning tanks, spray carts, hoses and toilet soakaway pits) were discharged directly into the lake. Since 2008, Sher Ethiopia has been working towards zero wastewater discharge, with all wastewater collected and treated in constructed wetlands. The effluent is then stored in reservoirs and eventually added to the irrigation water of the greenhouses. The Dutch government financed the research and implementation needed for the pilot project.

The Sher company initially had little confidence that this natural system would have such a positive effect, but during the pilot study they decided to implement it in all their greenhouses. At the end of 2016, 31 constructed wetlands were operational, treating 500 m^3 of water per day, which is reused within the facilities, drastically reducing the environmental impact (water footprint) of the company.

Source: Van Dien and Boone (2015).

Contributed by Frank van Dien (ECOFYT) and Angela Renata Cordeiro Ortigara (WWAP).

BOX 15.2 DECENTRALIZED RAINWATER HARVESTING IN SUWON CITY, REPUBLIC OF KOREA

Suwon City is a good illustration of how decentralized rainwater harvesting can be deployed, including in dense, built environments, where a central piped infrastructure is already in place (see OECD, 2015b) for more details and developments). This city of 1.1 million inhabitants has to procure most of its water from elsewhere. Suwon embarked on the "Rain City" project, in order to reduce its dependence on distant water sources. The project uses rainwater in preparation for future water shortages. The first phase of the project (2009–11) combined planning (including guidelines on the installation and operation of rainwater harvesting systems), education, and strong public finance support. The second phase (2015–2018) includes the installation of rainwater recycling facilities with a 10,000 m^3 capacity and 150 small rainwater tanks, with a city budget of KRW 10 billion (roughly US$9 million) (OECD, 2015b).

The oxygen demand was 'satisfied' by using large amounts of energy to encourage the growth of microbial biomass (sludge), which was separated from the system and used in agriculture or dumped at sea. Later developments saw extended aeration systems to reduce the final amount of biomass for disposal, as this was responsible for a large proportion of the treatment costs.

During the oil crisis in the 1970s, anaerobic digestion became the preferred method to treat wastewater and sludge, on account of the reduced amount of energy available. The 1980s and 1990s saw an increased interest in nutrient removal, mainly in the developed world, as nutrient discharge had led to the eutrophication of water bodies in many regions of the world. During the same period, significant advances were made in the use of more natural treatment systems, such as waste stabilization ponds and reed bed systems. These types of systems offer efficient reduction in pathogens with low capital and operational costs. Indeed, even in developed economies, they find a use in small-community treatment systems. The most recent trends have seen treatment systems that address the reduction of GHG emissions. In parallel, much research was undertaken, particularly in the developing regions of the world, on systems that focused on reducing the bacteriological hazards.

Additional details concerning various types of treatment technologies are provided in Table 4.2.

BOX 15.3 SEWER MINING IN SYDNEY, AUSTRALIA

The sewer pipe running through the golf course carries wastewater from about one thousand homes to the coastal town of Manly, where it receives primary (very basic) treatment and then gets dumped into the sea. The project was mining wastewater that not only would go unused, but would also add pollutants to the ocean. And as long as the golf club siphoned off flow during peak hours of toilet flushing and showering – the morning and evening – it would not interfere with the pressure and flow rate needed to get the remaining sewage to Manly.

The sewer-mining scheme has cut Pennant Hills' potable water use by 92%, which earned the club an award from Sydney Water. Due to the club's use of treated wastewater on-site, Sydney Water no longer needs to supply it with some 70,000 m^3 per year of drinking water.

In addition, the nitrogen in the sewage has virtually eliminated the need to fertilize the golf course: small amounts of nitrogen get added every time the greens are irrigated. The fertilizer savings are somewhat offset, though, by the need to add gypsum to the soil to counteract the extra sodium in the reclaimed water.

Overall, the system has proven to be a cost-effective way to drought-proof the links and reduce stresses on Sydney's water supply. And the golfers, apparently, are pleased.

Source: Extracted from Postel (2012).

15.7 Sewer mining and component separation

Active direct use of wastewater and the nutrients it contains has often been driven by necessity, but its use for recreation or other purposes has been documented in many developed regions (see Box 15.3).

New technologies are emerging that allow for the upgrading of wastewater treatment plants to 'factories' in which the incoming materials are deconstructed to units such as ammonia, carbon dioxide and clean minerals. This is followed by a highly intensive and efficient microbial re-synthesis process where the used nitrogen is harvested as microbial protein (at efficiencies close to 100%), which can be used for animal feed and food purposes (Matassa et al., 2015).

Another new approach has been proposed in which the used water is subjected to a procedure that allows the uptake of its organics and inorganics materials into fish biomass. The fish are harvested and processed to become a source of feed or food. The remaining water can be used for irrigation or discharged. Indeed, the organics and inorganics present in the incoming used water are removed to a large extent in the form of the harvested fish (Crab et al., 2012).

The key features of both of these concepts for treating wastewater is that they do not follow the route of destroying the nutritive value which is present in the used water. On the contrary, they add a form of renewable energy to allow aerobic microbes to upgrade the nutrients to microbial cells growing in flocs, and they harvest the latter by fish grazing on them. In the latter case, biomass is then processed to become of further use as feed or food.

Concerning the isolation and separation of useful wastewater components, it is likely that urine collection and use will become an increasingly important component of ecological wastewater management, as it contains 88% of the nitrogen and 66% of the phosphorus found in human waste (Maksimović and Tejada-Guibert, 2001; Vinnerås, 2001).

CHAPTER 16

UNESCO-IHP | Sarantuyaa Zandaryaa and Blanca Jiménez-Cisneros

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WATER REUSE AND RESOURCE RECOVERY

Sign warning of reclaimed water being in use

This chapter outlines a broad set of opportunities for the safe and beneficial use of treated and untreated wastewater and the recovery of useful by-products, including energy and nutrients. Business models and economic approaches are also presented, along with potential responses related to risk management, regulatory considerations, and social acceptance.

Water reuse is gaining momentum as a reliable alternative source of freshwater in the face of growing water demand, shifting the paradigm of wastewater management from 'disposal' to 'reuse and resource recovery'. Effective management practices, technological innovation and appropriate regulatory policies will offer further opportunities. Wastewater is also a potentially important source of recoverable energy, nutrients and other valuable materials.

Water reuse and resource recovery from wastewater has become a field where science and technological innovation are rapidly developing, with promising applications not only in safe reuse, but also in other non-conventional areas, such as by-products recovery, and for promoting environmental and economic benefits.

Figure 16.1 shows global water reuse after advanced (tertiary) treatment. However, it is important to note that, of all the wastewater produced worldwide, only a very small fraction actually undergoes tertiary treatment (see Prologue).

16.1 Beneficial reuse of water

Water reuse is economically feasible and attractive when there is a potential for cost recovery by treating wastewater to a water quality standard acceptable to users. Cost recovery from the sale of treated wastewater for irrigation is limited due to significant subsidies for irrigation, especially in developing countries. In industries, treated wastewater can be priced higher, mainly to achieve greater cost recovery rather than for profit (see Section 16.3).

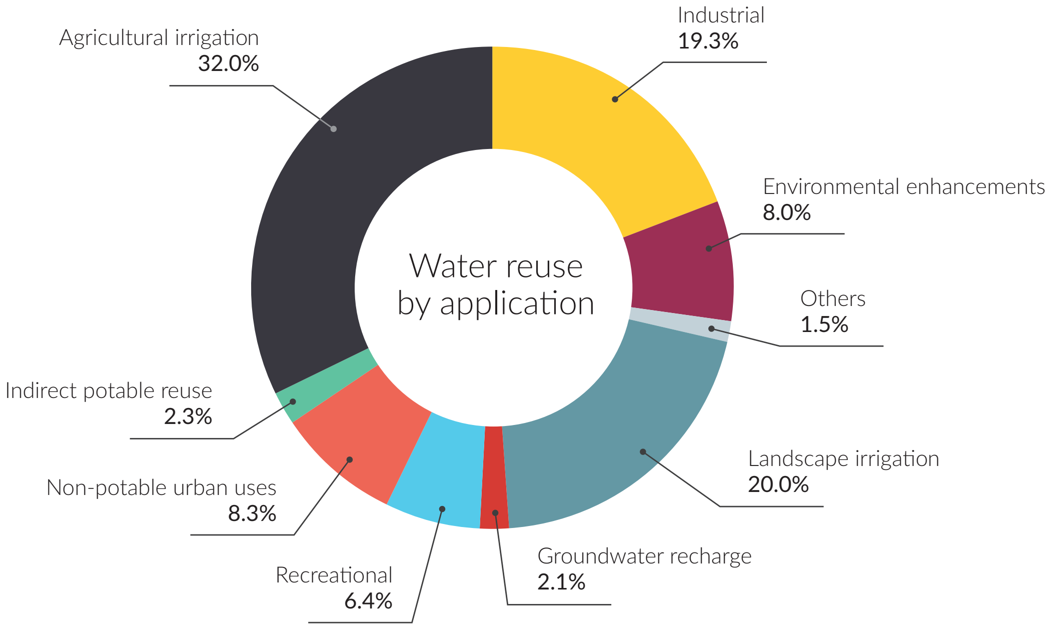
16.1.1 Water reuse in agriculture

Wastewater irrigation. Irrigation accounts for the majority of the treated, untreated and partially treated wastewater used worldwide (see Chapter 7). In Israel, for example, treated wastewater already accounted for 40% of all water used for irrigation in 2011 (OECD, 2011b).

The use of untreated or diluted wastewater for irrigation has taken place for centuries. The main challenge in using wastewater for irrigation is to shift from informal, unplanned uses of untreated or partially treated wastewater to planned safe uses. This requires location-specific drivers and 'business models' (Otoo and Drechsel, 2015; Saldias Zambrana, 2016; Scott et al., 2010), and safety measures like those outlined in the WHO's Sanitation Safety Planning guidelines (WHO, 2016b).

Wastewater use in aquaculture. The intentional use of wastewater in aquaculture (see Section 7.2.1 and Box 5.3) is declining worldwide due to safety concerns and loss of land areas close to urban markets, although it has been practiced for centuries in almost all regions of the world, notably in Asia. It has positive impacts on food production, as the nutritional benefits from wastewater-fed aquaculture are substantial (WHO, 2006a). Wastewater use in fishponds remains widespread in China, India, Indonesia and Viet Nam. Unintentional waste-fed aquaculture occurs in Bangladesh through fish farming in water bodies containing faecally contaminated water. Human excreta are still used in aquaculture in China, particularly in more remote rural areas, but this practice is declining. The intentional use of wastewater in aquaculture is not a traditional practice in Africa, but fish for human consumption are raised in faecally polluted lakes. Using wastewater to produce fish feed, like duckweed, offers a safer alternative. In Lima (Peru), the culture of fish tilapia for food in tertiary treated effluent was shown to create employment while improving water use efficiency in a desert environment (UNEP, 2002).

Figure 16.1 Global water reuse after advanced (tertiary) treatment: Market share by application



Source: Lautze et al. (2014, Figure 2, p. 5, based on Global Water Intelligence data).

BOX 16.1 THE UNIQUE EXPERIENCE OF DIRECT POTABLE REUSE (DPR) IN WINDHOEK, NAMIBIA

The use of reclaimed water was the only affordable option for the city of Windhoek to cope with the water shortage caused by population growth, increased demand and declining rainfall following the water crisis of 1957. This has led to the first full-scale application of DPR in the Wastewater Reclamation Plant in Windhoek, Namibia – the world's longest experience since 1969. During the more than 40 years of operation, the safety was verified by epidemiological studies and no health problems were reported. The advanced multi-barrier treatment process produces purified water of a quality that consistently meets all the required drinking water standards. The new plant, built in 2002, incorporates a substantial technological upgrade.

The plant's continued success is attributable to several factors, including: the vision and great dedication of the potable reclamation pioneers; the excellent information policy and education campaigns supporting buy-in; the absence of water-related health problems; a multiple-barrier approach; reliable operation and online processes and water quality control; and the near absence of practicable alternatives (Lahnsteiner et al., 2013).

BOX 16.2 THE BIGGEST UNPLANNED WATER REUSE CASE FOR HUMAN CONSUMPTION, MEXICO

The Tula Valley in Mexico is a clear case of unplanned water reuse. For more than 110 years, up to 52 m³/s of untreated wastewater from Mexico City has been used for irrigation of the Tula Valley. This has resulted in the incidental recharge of an aquifer, which is used as water supply for consumption and other activities for around 500,000 people. Thanks to natural processes, the water quality is compatible as a supply source of water. The recharging of the aquifer also had a positive impact on local environmental, social, and economic conditions, and contributed to the development of a poor region (Jiménez-Cisneros, 2008).

BOX 16.3 DECENTRALIZED WATER MANAGEMENT AND WASTEWATER USE: THE EXPERIENCE OF SAN FRANCISCO, CALIFORNIA

The San Francisco Public Utilities Commission (SFPUC) in the USA is embracing decentralized water treatment systems to provide supplemental water and wastewater services. In the absence of federal regulation, the SFPUC launched a local programme for regulating on-site water use called the Non-potable Water Program, which creates a streamlined process for new developments to collect, treat and reuse alternative water sources, including grey water and blackwater, from large-scale commercial and residential buildings in order to meet their non-potable needs. It establishes guidelines for developers interested in installing non-potable water systems in buildings. Subsequently, the SFPUC realigned governmental policies and created a new regulatory framework by collaborating with the San Francisco departments in charge of Building Inspection and Public Health.

SFPUC allowed for micro-markets to emerge when two or more buildings share, buy or sell water without a public agency providing the service. The programme shifts the burden of operation, maintenance and water quality compliance to the private sector while the public sector maintains oversight to ensure the protection of public health and the public water system (OECD, 2015b).

Contributed by Xavier Leflaive (Water Team Leader, OECD Environment Directorate).

16.1.2 Urban water reuse

Reclaimed water (after ‘fit-for-purpose’ treatment) offers opportunities for a sustainable and reliable urban water supply (see Chapter 5), as a growing number of cities are relying on more distant and/or alternative sources of water to meet the increasing demand.

Indirect potable reuse (IPR) is based on infiltration of treated wastewater into surface waters and groundwater, where natural processes (filtration, adsorption, UV exposure, sedimentation, dilution, natural die-off) further clean the water (see Box 5.2). After re-abstraction, the water is treated like any other source of drinking water. IPR thus offers a feasible option to augment other drinking water sources, provided strict monitoring is in place to achieve compliance with drinking water standards and guidelines. Singapore’s NEWater (see Box 16.9) is an example of indirect potable reuse, but due to public acceptance concerns, only a small portion of the reclaimed water is injected into Singapore’s freshwater reservoirs for indirect reuse.

Direct potable reuse (DPR) is gaining interest with recent developments in the availability and affordability of appropriate water treatment technologies (see Section 5.5.1). Direct potable water reuse requires the most rigorous water quality monitoring to eliminate any risks to the public health and to meet strict water quality requirements. In Windhoek, Namibia, which lacks affordable water alternatives, up to 35% of the city’s wastewater is treated and blended with other potable sources to increase the drinking water supply (see Box 16.1) (Lazarova et al., 2013).

Unplanned potable water reuse for urban supplies still occurs through the discharge of untreated or insufficiently treated wastewater into surface and groundwater sources (see Box 16.2) and remains a challenge, especially in densely populated river basins all over the world.

Non-potable reuse. The main factor for the rapid expansion of non-potable urban reuse (see section 5.5.2) is that the water does not necessarily need to comply with strict water quality standards (i.e. ‘fit-for-purpose’ treatment). However, risks related to direct contact with reclaimed water and cross-connection contamination are a concern to be dealt with through strict control measures. The high costs of building and maintaining adequate infrastructure to keep the reclaimed water separate from potable water (i.e. dual distribution systems) can impose a financial constraint. However, such systems, which can easily be integrated in new urban developments, are currently expanding in Europe, Japan and the USA (see Box 16.3) (Asano et al., 1996; Grigg et al., 2013; OECD, 2015b).

16.1.3 Industrial water reuse

Industrial water reuse (see Chapter 6) involves recycling industrial wastewater for industrial uses (process water) and non-industrial uses (irrigation, landscape irrigation, non-potable urban uses, etc.). Industries can also use treated municipal wastewater. Recycled industrial water has been used as process water in power stations, textile manufacturing, paper industry, oil refineries, heating and cooling, and steelworks for a long time. New applications of industrial water reuse are also emerging, such as the use of treated wastewater as cooling water in big data centres (for example, the Google data centres in Belgium and Georgia, USA). More efficient water recycling and process technologies can ultimately lead to the closing of the water loop in industries (see Box 14.2), while reducing water use by more than 90% (Rosenwinkel et al., 2013).

16.1.4 The 'fit-for-purpose' concept

'Fit-for-purpose' water reuse means that the required treatment level is defined by water quality requirements of the intended use. Most non-potable reuse options require a quality lower than that of drinking water, so that secondary treatment is often adequate (see Section 5.5). However, barriers to wider applications of this approach remain, including the lack of appropriate and flexible regulatory and institutional frameworks. Potential health and environmental risks can also be reduced through appropriate safety control measures, such as the multiple-barrier approach (WHO, 2006a) (see Section 16.4).

The 'fit-for-purpose' water reuse concept has been successfully applied in the West Basin Municipal Water District in El Segundo, California, USA (see Box 12.2), which treats water to five distinct levels of quality suited for different specific uses (Walters et al., 2013).

16.1.5 Wastewater use for environmental benefits – Replenishing water resources

Common uses of wastewater for environmental benefits include the replenishment of water resources through groundwater recharge, river flow restoration, water augmentation in lakes and ponds, and restoration of wetlands and biodiversity (see Chapter 8).

Aquifer recharge. Artificial aquifer recharge through the intentional injection of treated wastewater for subsequent recovery or to enhance ecosystems is a common practice. The main limitations are related to the aquifers' storage capacity and recharge rate. Aquifer recharge offers several benefits, including water supply augmentation and storage, maintenance of wetlands, and saline intrusion prevention.

The Torreele Facility in Belgium produces high-quality infiltration water for indirect potable use via groundwater recharge in the dune aquifers of St. André, while offering environmental benefits such as saline water intrusion prevention, sustainable groundwater management and the enhancement of natural values (Van Houtte and Verbauwhede, 2013). Unintentional aquifer recharge with untreated or insufficiently treated wastewater still occurs in many areas. This needs special attention, as it can lead to human and environmental health risks.

BOX 16.4 PHOSPHORUS (P) RECOVERY GAINING MOMENTUM

The most common form of phosphorus recovery from wastewater takes place as struvite precipitation. The most attractive financial options are those where the recovery takes place early and allows the operator to save on the costly removal of unwanted struvite within the treatment system. However, in view of the sale of the recovered P, there are no financially attractive options yet that can compete directly with phosphate-ore-based fertilizers in the market (Schoumans et al., 2015). Short-term price volatility, long-term price hikes, and increasing concern for P insecurity on the political agenda (relating to concerns of food insecurity and environmental degradation) may provide additional incentives for recycled P over unsustainable mining.

Marketing strategies for recovered phosphorus

The Ostara Company in Canada, specialized in private–public partnerships with wastewater treatment plants, has successfully applied P-recovery as crystalline struvite pellets branded 'Crystal Green', which can be used as a commercial fertilizer, by transforming the unwanted struvite formation in the pipes. Revenue from the fertilizer sale is shared with the city to offset the costs of the facilities.

The Austrian-based company ASH DEC Umwelt AG developed a technology for sludge incineration that completely destroys pathogens and organic pollutants, followed by a chemical and thermal treatment to produce an ash-based multi-nutrient fertilizer, sold under the PhosKraft® brand. Considering reduced disposal costs, the production price is comparable to commercial fertilizers. The payback period for investments in a full-scale plant was estimated at 3–4 years (Drechsel et al., 2015a).

Contributed by Pay Drechsel (IWMI); Angela Renata Cordeiro Ortigara (WWAP); and Dirk-Jan Kok and Saket Pande (TU Delft).

BOX 16.5 RECOVERY OF ENERGY AND BIOFUELS FROM BIOSOLIDS: THE COMPREHENSIVE (LEGISLATIVE AND FINANCIAL) APPROACH OF JAPAN

In Japan, although more than half of biosolids are recovered, only 15% of their potential biomass energy is being utilized. The Japanese Government has set a target to increase this percentage to 30% by 2020 by means of legislative approaches, financial aid, promotion of innovation, tax reductions and standardizations of biosolid by-products.

The new Sewerage Act of Japan of 2015 requires sewage operators to utilize biosolids as a carbon-neutral form of energy. The full potential of the country's 2.3 million tonnes of biosolids produced each year by 2,200 operating wastewater treatment plants can generate 160 GWh electricity per year. In 2016, 91 plants recovered biogas for electricity and 13 produced solid fuels. A leading example is the city of Osaka, which produces 6,500 tonnes of biosolid fuel per year from 43,000 tonnes of wet sewage sludge for electricity generation and cement production. As a financial aid to support sewage operators investing in the energy reuse from biosolids, a feed-in tariff is paid for the electricity generated from biosolids at a fixed price per kWh.

The Government of Japan promotes innovation by subsidizing breakthrough technologies in biosolids reuse. Private financing is also promoted through a special depreciation measure to reduce the tax burden on private firms investing in energy reuse equipment of wastewater treatment plants. By-products like biosolid fuel are being standardized in order to create a market for them.

*Source: Ministry of Land, Infrastructure, Transport and Tourism of Japan**

Contributed by Takahiro Konami (UNESCO-IHP).

*For further information, see www.mlit.go.jp/en/index.html

16.2 Resource recovery from wastewater and biosolids

16.2.1 Nutrient recovery

Recovering nitrogen (N) and phosphorus (P) from sewage or sewage sludge requires advanced technologies, which are still in the stage of development, yet have made significant progress in recent years (see Section 15.7). There are an increasing number of cases (e.g. Bangladesh, Ghana, India, South Africa, Sri Lanka, etc.) where municipalities engage in septage sludge dewatering, safe co-composting and pelletization (Nikiema et al., 2014). P-recovery from on-site treatment facilities such as septic tanks and latrines can be technically and financially feasible by transforming septage into organic or organic-mineral fertilizer. Moreover, faecal sludge presents a relatively lower risk of chemical contamination compared to sewerage biosolids.

Extractable P mineral resources are predicted to become scarce or exhausted in the next 50 to 100 years (Steen, 1998; Van Vuuren et al., 2010). Thus, P-recovery from wastewater is becoming an increasingly viable alternative (see Box 16.4). An estimated 22% of global P demand could be satisfied by recycling human urine and faeces worldwide (Mihelcic et al., 2011).

Despite significant technological advances in nutrient recovery from wastewater and sludge, business opportunities remain limited, mainly due to lacking markets. The low nutrient content in biosolids, in particular N, does not allow for profitable sales on the market. Only 5–15% of the available N in the wastewater can be recovered, while it is possible to capture 45–90% of the P in wastewater (Drechsel et al., 2015a). Hence, the process will probably be driven by various technological options to recover P from struvite precipitation, sludge and incineration with different levels of costs and efficiencies.

BOX 16.6 EXAMPLES OF BUILDINGS HEATED AND COOLED WITH WASTEWATER

The 2010 Winter Olympic Village, Vancouver, Canada. The former 2010 Winter Olympic Village, later converted to apartment buildings, is heated with effluents from the wastewater treatment plant of a nearby village (Godfrey et al., 2009).

Wintower high-rise building at Winterthur, Switzerland. Wastewater is used to heat the 28-storey Wintower in cold winter months and to cool the building in summer. About 600 kW heating energy is extracted from wastewater taken from the sewer. Wastewater is also used for cooling in summer, absorbing energy from the building. This system is a demonstration of wastewater use as a carbon-neutral energy source for the year-round heating and cooling of buildings (HUBER, n.d.).

> **Energy recovery has significant business potential in terms of reducing energy use, operational costs and its carbon footprint**

16.2.2 Energy recovery

Wastewater plays a significant role in the water-energy nexus. Although wastewater collection and treatment require significant amounts of energy, wastewater itself can be a source of energy and its vast potential is underexploited (WWAP, 2014). The chemical, thermal and hydraulic energy contained in wastewater can be recovered in the form of biogas, heating/cooling and electricity generation through on-site and off-site processes (Meda et al., 2012). Technologies exist for on-site energy recovery through sludge/biosolids treatment processes integrated in wastewater treatment plants. The off-site energy recovery involves sludge incineration in centralized plants through thermal treatment processes. Emerging technologies include microbial fuel cells to generate bioelectricity from sludge using bacteria, aerobic granular sludge technology, anaerobic ammonium oxidation (Anammox), and biomass manipulation. There are also opportunities for combined energy and nutrient recovery. Although the technologies are available, their widespread application is hindered by limited market opportunities and other barriers related to economies of scale.

Energy recovery has significant business potential in terms of reducing energy use, operational costs and its carbon footprint. Reducing the carbon footprint of wastewater treatment plants can increase revenue streams through carbon credits and carbon trading programmes (Drechsel et al., 2015a).

BOX 16.7 TOTAL ENERGY RECOVERY POTENTIAL OF SEWAGE SLUDGE ENCOMPASSING ANAEROBIC DIGESTION AND THERMAL CONVERSION IN ZÜRICH, SWITZERLAND

The latest Outotec plant, using sewage sludge from Zürich, is an example of total energy recovery with efficient energy conversion and nutrient recovery, setting new global standards for energy conversion efficiency. Efficient energy conversion is possible with anaerobic digestion, producing biogas and/or electricity, and with combustion, producing steam and heat. Each of the two processes yields about 50% of the energy potential of sewage sludge, adding up to a total yield of 6 MWh per tonne of dry sludge. There are different options for use, like upgrading the biogas to pipeline grade quality and feeding it to the gas grid, or converting the steam into electricity and heat for use within the wastewater treatment plant. The city of Zürich adopted this model in 2015. Phosphorus recovery is a legal obligation in Switzerland since January 2016. The Zürich Water Board will implement P-recovery once the most appropriate technology will be selected.

Source: Outotec GmbH & Co (n.d.).

Contributed by Ludwig Hermann (Outotec GmbH & Co).

Biogas production. Biogas production from chemical energy contained in organic substances in wastewater through the anaerobic digestion of biosolids for subsequent electricity and heat generation is the most common application of on-site energy recovery. A substantial portion of the energy and heat demand of wastewater treatment plants can be met through energy recovery from biosolids (see Box 16.5).

Heat recovery. Thermal energy contained in wastewater can be extracted for space heating and cooling. There are several applications of wastewater use for heating/cooling in residential and commercial buildings, public spaces and industrial plants (see Box 16.6).

Hydraulic energy. Placing turbines in wastewater streams can generate electricity, but this process is restricted due to the low-elevation locations of most wastewater treatment plants. The As-Samra Wastewater Treatment Plant in Jordan (see Section 10.3.4) is well-known for using elevation differences between the city and the plant, as well as between the plant inlet and outlet, using two turbines upstream and downstream of the plant. About 80–95% of the plant's energy requirement is met by these turbines (1.7 and 2.5 MW, respectively) and the biogas generated from sludge (9.5 MW) (Otoo and Drechsel, 2015).

Transitioning to energy neutrality and net energy producers. With the optimization of energy use in wastewater treatment processes and the recovery of energy from wastewater and biosolids, there are opportunities for wastewater treatment facilities to transition from major energy consumers to energy neutrality, or even to net energy producers (see Box 16.7).

16.2.3 Recovery of high-value by-products

Metals and other inorganic compounds in wastewater – mainly in industrial effluents – present opportunities not only for recovery of high-value by-products, but also for reducing health concerns and environmental pollution caused by their disposal. Effluents from mining and electrical industries can contain certain traces of heavy metals (e.g. gold, silver, nickel, palladium, platinum, cadmium, copper, zinc, molybdenum, boron, iron and magnesium). Their recovery has been explored through various electrochemical extraction processes, which are often energy- and chemical-intensive. These applications are limited to specific large-scale industries. The recent development of bio-electrochemical technology may provide a new approach for efficient metal recovery (Wang and Ren, 2014).

The use of environmental friendly microalgae is being explored to produce high-value products such as transportation biofuels, bio-plastics, bio-chemicals, nutrition supplements for humans and animals, antioxidants, and cosmetic ingredients from resources dissolved in wastewater (see Box 16.8).

BOX 16.8 WASTEWATER AS A SOURCE OF HIGH-VALUE HYDROCARBONS THROUGH MICROALGAE

- **Wastewater to liquid transportation fuel.** The concept of producing biofuel for transportation is based on the conversion of nutrients in wastewater into microalgae biomass (i.e. wastewater-fed microalgae), which in turn are converted into biofuel. This approach provides multiple benefits, and can be used for cleaning wastewater, capturing carbon dioxide and producing alternative sustainable energy without competing with agriculture for water, fertilizer and land. In the USA, NASA's Offshore Membrane Enclosures for Growing Algae (OMEGA) project is exploring the feasibility of producing aviation fuels by farming microalgae in floating offshore pods that are 'fed' by wastewater from cities (Trent, 2012).
- **Bio-oil from wastewater algae**. New Zealand's National Institute of Water and Atmospheric Research (NIWA) has demonstrated the commercial feasibility of producing bio-oil from wastewater-grown microalgae at the Christchurch Wastewater Treatment Facility (Craggs et al., 2013). Carbon dioxide is added into 'high-rate algal ponds' to facilitate the energy-efficient conversion of algal biomass to bio-oil.*
- **Production of biodegradable bioplastics.** Biodegradable bioplastics produced from wastewater microalgae have the potential to replace traditional petroleum-based plastics at lower costs. Once it becomes economically feasible, this process could revolutionize the polymer space, offering business opportunities for the production of bio-based sustainable products while bringing additional benefits such as carbon sequestration, smaller ecological footprints, reduced petroleum dependence, and improved end-of-life options.**
- **Production of cosmetic ingredients from wastewater by using microalgae**. Since July 2015, the Algae Biomass Energy System Development Research Center at the University of Tsukuba in Japan is conducting research on algae biomass and industrial applications for synthesizing algae-derived oils, thus creating a new 'algae industry', combining biofuel production, wastewater treatment, and algae-derived oils for cosmetics and medical products.

*For further information, see www.niwa.co.nz/freshwater-and-estuaries/research-projects/bio-oil-from-wastewater-algae

** For further information, see http://algix.com/sustainability/our-solution/

16.3 Business models and economic approaches

Wastewater use offers a double value proposition if, in addition to the environmental and health benefits of wastewater treatment, financial returns are also possible. The size of the revenue streams depends on the types of resources that can be recovered from wastewater. Wastewater use itself becomes all the more competitive when freshwater prices reflect also the opportunity cost of using freshwater whereas pollution charges reflect the cost of removing pollutants from wastewater flows, not to mention the potential economic damage of inaction.

Wastewater treatment has primarily followed a ‘social business model’, with its main economic justification centred on safeguarding public health and the environment. Yet, there is a range of options to move from a ‘revenue model’ to a ‘business model’ (Drechsel et al., 2015a), with cost and value recovery offering a significant advantage from a financial perspective, not only for private sector engagement, but also to the public sector.

Intersectoral water transfers (or ‘water swaps’) aim to provide treated water to farmers for irrigation, for example, in exchange for freshwater for domestic and industrial purposes (Winpenny et al., 2010). This business model can also be applied to water swaps with other water-intensive users, such as golf courses. Water swaps do not increase the overall water availability, but can allow for the allocation of more freshwater to high-value uses.

Replenishing natural capital is based on benefit sharing, where the agency responsible for drinking water pays an amount to the entity responsible for partial treatment and medium-term storage, generally through groundwater recharge. This business model benefits the drinking water agency when the potential benefits compare favourably with the development of alternative freshwater supplies. Operational cost recovery will depend upon the prevalent price for fresh/potable water. Private stakeholders neighbouring the groundwater recharge zone can benefit as well by gaining access to higher groundwater levels (and they can potentially sell the water through private tankers) (Rao et al., 2015).

On-site value creation is based on wastewater aquaculture. When fish production takes place within a pond-based treatment process, the reuse value proposition can be integrated through the absorption of nutrients from the wastewater into biomass (e.g. duckweed) that can in turn feed the fish. The business model combines a low-cost treatment solution with potentially high revenue generation, thus allowing for a move beyond cost recovery (Rao et al., 2015).

Marketing reclaimed water is arguably the simplest business model, where partially treated (‘fit-for-purpose’) wastewater is made available to the user at a lower cost than treated water. Although low freshwater prices make it often difficult to charge appropriately for reclaimed water, and thus to achieve full cost recovery, several successful examples have been documented (Lazarova et al., 2013).

Hedging future water markets is based on the premise that the demand for reclaimed wastewater by industries and agriculture will increase in the future. The concept is to match future water ‘buyers’ with suppliers of treated wastewater by trading water entitlements, thus securing parts of the investment capital beforehand for wastewater treatment projects (Rao et al., 2015).

Examples of water reuse cases with business potential are presented in Table 16.1.

The potential for cost recovery from wastewater use increases with greater treatment levels, which translates to improvements in water quality and/or the ability to recover additional resources and materials. Recovering several products from wastewater enables new opportunities, enhances revenue, and moves the business up on the economic value proposition ladder (see Figure 16.2).

At present, the possibilities for nutrient and energy recovery are among the most advanced in terms of technical and financial feasibility, as described in the various examples provided in the previous section (16.2). However, there is increasing potential for enhancing these processes (see Chapter 17) and, collectively, such advances are expected to provide further opportunities for cost recovery in wastewater management and reuse.

Table 16.1 Examples of water reuse cases with business potential

Business model	Business case location	Business concept, products/ services and beneficiary	Treatment type	Drivers and opportunities
Water swap	Mashhad City, Iran	Agreement between regional water company and association of farmers for water exchange. Transfer of farmers' water rights from dams and groundwater in exchange for treated wastewater	Secondary treatment	Water scarcity and the need to reduce stress on freshwater
Replenishing natural capital	Hoskote Lake, Bangalore, India	Department of minor irrigation diverting untreated sewage from one part of the city to another. The recharging of a dry lake and groundwater wells benefits small farmers and households around the recharge zone	No treatment except natural processes	Need for lake restoration and replenishing depleting groundwater table and drying wells
On-site value creation based on aquaculture	Mirzapur, Bangladesh	Partnership of Hospital Trust and NGO to treat wastewater to produce duckweed as fish feed and cultivate crops for local market	Tertiary treatment, including nutrient removal through duckweed	Partnership between hospital complex and the technology promoter and high demand for fish in the region
Marketing reclaimed water	Gaborone City, Botswana	Treatment of wastewater from Gaborone and reuse for irrigation of Glen Valley farms and river flow augmentation	Secondary treatment	Frequent droughts and chronic water scarcity
Hedging for future water markets	Prana Sustainable Water, Switzerland	Wastewater treatment pre-financed by future water sales via contractual agreements to secure water shares and finances	Secondary or tertiary treatment	Knowledge management on water markets, water trading and commodity pricing along with strong partnerships

Source: Adapted from Drechsel et al. (2015a, Table 11.2, pp. 202–203).

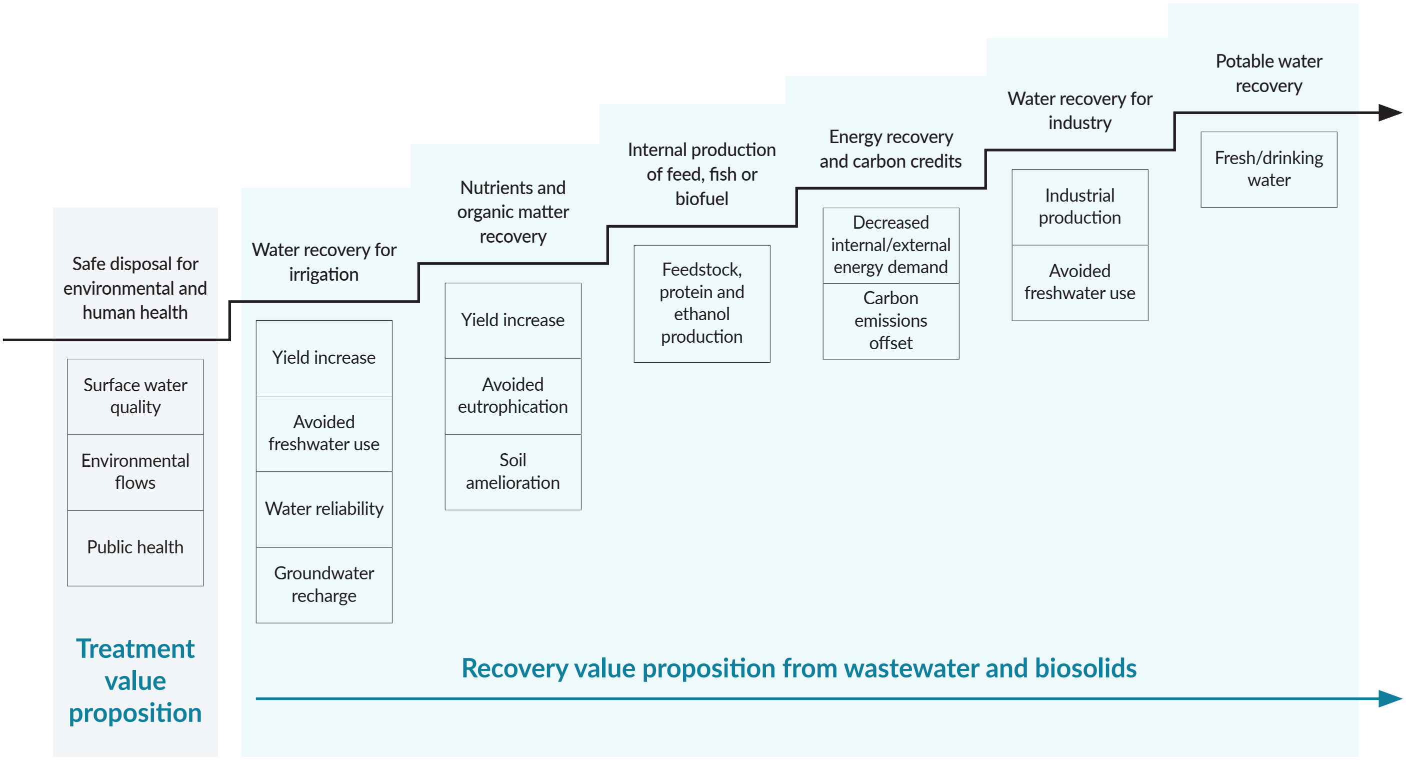
16.4 Minimizing risks to human health and the environment

Due to potential risks to human health, water reuse for human consumption (i.e. drinking water) requires the most rigorous approach, including strict regulations and robust monitoring, assessment and compliance programmes.

Exposure of vulnerable groups to partially treated, or untreated, wastewater, especially in agricultural irrigation, requires particular attention (see Section 7.2.2). The most vulnerable groups include farmers, field workers and nearby communities through direct contact with wastewater, and consumers through the consumption of wastewater-grown crops. Limited awareness of health risks associated with wastewater use, due to poverty and low education, further contributes to these risks, in particular in developing countries. Women are especially vulnerable (Moriarty et al., 2004).

Appropriate wastewater treatment, in combination with the application of water quality standards in wastewater-irrigated agriculture should be sufficient to protect

Figure 16.2 Ladder of increasing value propositions for reuse with increasing investments in water quality or the value chain



Source: Drechsel et al. (2015a, Fig. 1.2, p. 8).

public health. However, in the majority of low-income countries, where most of the wastewater produced undergoes little or no treatment, alternative approaches are necessary to prevent pathogens from entering food production chains. The *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture* (WHO, 2006a) recommend a multiple-barrier approach to protect public health where non-treatment options are implemented (see Box 7.1).

Potential long-term effects of emerging pollutants on human health and ecosystems (see Section 4.1) as a result of wastewater use are not known yet (UNESCO, 2016b). There is a need for further research regarding the risks to human health and the environment caused by chemicals and emerging pollutants in wastewater (see Section 17.2).

The environmental health risk is an important aspect of wastewater use (see Section 6.2.2). Yet, the issue is often neglected. Comprehensive environmental monitoring programmes are needed, not only to evaluate and assess risks, but also to develop appropriate environmental protection policies.

> Water reuse is economically feasible and attractive when there is a potential for cost recovery by treating wastewater to a water quality standard acceptable to users

16.5 Regulations for water reuse

Earlier regulations for wastewater use were based on wastewater treatment measures, whereas more recent ones focus on specific water quality standards and criteria for different types of use, in order to protect human and environmental health. However, the cost of advanced wastewater treatment to conform to high water quality standards remains unaffordable for many developing countries. The multiple-barrier approach (see Box 7.1) responds to this challenge, as it is based on risk assessment and management.

BOX 16.9 SINGAPORE NEWATER: COMPREHENSIVE EDUCATIONAL AND AWARENESS CAMPAIGN

The Singapore Public Utilities Board (PUB)* used a comprehensive approach, including the ABC Waters Programme for public awareness; the 3Ps (*People, Public, Private*) education programme; and the NEWater Visitor Centre. The 3Ps programme included community leaders, journalists, business groups, government agencies and the media. The NEWater Visitor Centre was built to offer public education programmes and information dissemination. It attracted over 800,000 domestic and foreign visitors. In order to reduce negative public perception and psychological fear and stigma, PUB translated technical information and terms into simple language; for example, the term 'wastewater and sewage' was changed into 'used water', and 'sewerage treatment plant' into 'water reclamation plant'. Information was also provided in simple diagrams and graphs, as well as through entertaining tools for community outreach such as the mobile game 'Save My Water'. Social acceptance regarding wastewater increased as a result of these educational efforts for awareness-raising and outreach.

*For further information, see www.pub.gov.sg/

Source: PUB.

> **At present, the possibilities for nutrient and energy recovery are among the most advanced in terms of technical and financial feasibility**

Wastewater use guidelines need to be feasible to implement in terms of both technological and economic possibilities; enforceable through appropriate policies and programmes; and realistic for specific local conditions, taking account of economic, sociocultural and environmental factors. The human health and environmental protection measures need to be tailored to suit the local balance between affordability and risk.

Various guidelines for wastewater use for irrigation have been developed at the international and national levels. The most important criteria include health risk-based parameters, including microbiological standards for wastewater use such as the absence of faecal indicator bacteria, and physio-chemical parameters for treated wastewater, measuring the presence of total suspended solids (TSS), nutrients and heavy metals. Guidelines can also include restrictions based on irrigation practices according to the origin and end use of wastewater, such as crop restriction, irrigation techniques and human exposure control.

Developed countries set technical standards for microorganisms and chemicals. Such strict limit values require considerable monitoring and enforcement efforts. On the other hand, regulations in developing countries focus on use restrictions such as restricting wastewater irrigation for vegetables for direct human consumption and/or requiring a minimum time interval between irrigation and crop harvest. Such use restrictions cannot be monitored without functioning oversight agencies. Consequently, some countries, such as Mexico and Tunisia, have adopted guidelines based on use restrictions combined with easy-to-measure limit values.

> **Various guidelines for wastewater use for irrigation have been developed at the international and national levels**

One of the internationally applied guidelines for wastewater use is the *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture* (WHO, 2006a). The wastewater quality guidelines for agricultural use developed by FAO (1985; 1992) focus on evaluating the suitability of water for irrigation and identifying possible restrictions in use. Effective policies and regulations for wastewater use and resource recovery are mostly lacking at the national level, being only implemented in a small number of countries, including Israel, Jordan, Mexico, Tunisia and Turkey, where wastewater irrigation is a well-established practice.

16.6 Social acceptance of wastewater use

The use of wastewater can encounter strong public resistance due to a lack of awareness and trust with regard to the human health risks. Other factors include different cultural and religious perceptions about water in general and/or using treated wastewater. Whereas public health and safety concerns have traditionally been the main reason for public resistance to wastewater use, cultural aspects (see Box 16.10) and consumer behaviour seem to be the overriding factors in most cases today, even when the reclaimed water resulting from advanced treatment processes is entirely safe. Aesthetic aspects of reclaimed water, such as colour, odour and taste, also play an important role in public acceptance.

Awareness raising and education are the main tools to overcome social, cultural and consumer barriers and to significantly contribute to building trust among consumers and changing public perception about wastewater use. Such awareness campaigns need to be tailored to consumers with different cultural and religious backgrounds. Awareness and education programmes also need to target all age groups to be effective. Furthermore, they need to be tailored to local circumstances and needs. Branding and information dissemination is another important aspect, contributing to a positive public perception of reclaimed water, as well as recovered resources such as fertilizers. For example, in Singapore, reclaimed water is branded as 'NEWater' at a limited scale (see Box 16.9). Robust regulatory and monitoring frameworks ensuring human health safety are key to building consumer trust and changing public perception.

BOX 16.10 CULTURAL IMPLICATIONS OF WASTEWATER REUSE IN FISH FARMING IN THE MIDDLE EAST

The reuse of wastewater in fish farming is widely practiced to varying degrees in different regions of the world. A full-scale demonstration study in Egypt was conducted to use treated wastewater in fish farming and for irrigation of crops and trees. The treated wastewater was carefully monitored for microbial pathogens, parasites, and toxic chemicals in the water and the fish. In spite of the fact that the produced fish were quite suitable for human consumption, consumers in Egypt did not accept them.

Source: Mancy et al. (2000).

CHAPTER 17

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KNOWLEDGE, INNOVATION, RESEARCH AND CAPACITY DEVELOPMENT

Testing water quality in Beaver Lake in Minnesota

This chapter offers a review of trends in knowledge, research, innovation, capacity building and wastewater management, with a focus on current gaps and barriers. Responses to these challenges are presented in terms of capacity development, public awareness and improved collaboration, highlighting the potential for improving cost recovery and applying technological responses at appropriate scales.

17.1 Trends in research and innovation

With innovation and technological development evolving rapidly, there is a growing impetus for a paradigm shift towards wastewater management as part of a circular economy. Rather than thinking of reusing water as a costly add-on to wastewater treatment plants, the concept of converting them into 'resource recovery factories' that will use wastewater and sludge as a raw material and recover valuable products for marketing to end users is gaining increasing attention.

The evolution of wastewater management, especially in developed countries, has been tied to fighting epidemics and major technological breakthroughs. The nineteenth century's basic activated sludge technologies (treating wastewater using micro-organisms to remove organic matter from sewage) allowed the transition from "the sanitary dark ages" to "the age of sanitary enlightenment and industrial revolution" (Cooper, 2001). Technological developments in the late twentieth century focused on nutrient removal — nitrogen and phosphorus — to deal with the widespread problem of eutrophication and reduce environmental impacts of wastewater. Around the turn of the twenty-first century, with ever-increasing wastewater treatment requirements and institutional management capacities, the research and technological focus shifted to advanced processes in order to comply with more stringent regulations and effluent standards. Future research and innovation trends in the field of wastewater will probably focus on resource recovery to reinvent the economics of the treatment and disposal of wastewater and sludge. Competing demands for water and other natural resources are also driving research and innovations in wastewater technology and management.

The latest major technological innovations in wastewater treatment (see Box 17.1) are mainly aimed at improving treatment efficiencies (Brdjanovic, 2015; Qu et al., 2013; Van Loosdrecht and Brdjanovic, 2014).

While in some parts of the developed world new treatment plants are constructed based on cutting-edge technologies, there is an increasing call for appropriate technologies matching the institutional and resource constraints of low-income countries, such as technologies which can operate with limited external energy needs and lower installation, operation and maintenance costs than activated sludge systems, while achieving the same performance targets (Libhaber and Orozco-Jaramillo, 2012) (see Chapter 15).

17.2 Knowledge, research, technology and capacity-building gaps

The use of existing technologies requires financing, technical capacity and infrastructure, which developing countries often lack. It also requires knowledge transfer, information sharing and capacity-building through education and training to support the sustainability of technology applications. These knowledge, technology and capacity gaps should be assessed through a gap and capacity analysis that will facilitate the required technology transfer, education and capacity-building efforts where needed.

The extremely low level of secondary and advanced wastewater treatment in developing countries indicates an urgent need for technological upgrades in wastewater treatment and safe use options to support the achievement of SDG Target 6.3 (see Chapter 2). Appropriate and affordable technologies need to be transferred from developed to developing countries, supported

> Future research and innovation trends in the field of wastewater will probably focus on resource recovery

BOX 17.1 INNOVATIONS IN WASTEWATER TECHNOLOGY AND RESEARCH

Membrane filtration. Advances in membrane technology have not only reduced human and environmental health risks associated with treated wastewater, but also opened new opportunities for wastewater use, such as potable reuse. The use of membrane technologies (reverse osmosis, microfiltration, ultrafiltration, etc.) is becoming increasingly common for tertiary or advanced treatment, especially in developed countries, as membranes continue to improve and operational costs decrease.

Membrane bioreactors (MBRs) are an emerging technology, resulting from innovations to intensify the membrane separation by incorporating it with the activated sludge process. Recently, the number of plants with MBR technology is on the rise (Van Loosdrecht and Brdjanovic, 2014). MBRs offer advantages such as compactness, flexibility and ability to operate reliably under remote control.

Microbial fuel cells, a technological innovation based on bio-electrochemical processes of bacteria, have started to find applications in wastewater treatment over the past decade, in order to harvest energy (electrical current) by utilizing anaerobic digestion that mimics bacterial interactions found in nature. This technology can significantly reduce treatment process costs and the amount of leftover sludge. However, given the challenges in scaling up for practical application, further research and technological improvements are needed to overcome the high energy requirements.

New developments in biological treatment processes have found successful application due to the high efficiencies and low investment and operational costs. Examples include innovative processes for improved nitrogen removal such as SHARON® (single reactor system for high-activity ammonium removal over nitrite), ANAMMOX® (anaerobic ammonium oxidation) and BABE® (bio augmentation batch enhanced), as well as mineral crystallization processes for phosphorus recovery and reuse. Granular sludge treatment processes are also emerging by using engineered microbial structures. The first granular sludge process is commercialized under the name of NEREDA®.

Nanotechnology is an emerging and growing field with potentially promising applications in water purification and wastewater treatment, as well as in water quality and wastewater monitoring (Qu et al., 2013). Presently, nanotechnology applications in water and wastewater treatment focus on technology maturation and full-scale demonstration.

Innovative wastewater monitoring and control systems are finding application as technologies improve. The most promising technological advances include: innovative monitoring techniques based on new sensors, computerized telemetry devices, and innovative data analysis tools. Research on sensor and system control is advancing rapidly. New methods to control wastewater treatment are continually introduced, including the use of mobile applications to operate the SCADA (Supervisory Control and Data Acquisition) system for remote monitoring and control of wastewater systems.

Natural treatment systems (constructed wetland systems) are becoming more attractive as innovative natural solutions to complement existing technological limitations, with research increasingly focusing on natural processes.

Modelling has become an important aspect of new research developments in the field of wastewater, as fundamental knowledge on microbiology and bio-chemistry advances and the computational capacity improves. Modelling not only allows the transfer of scientific knowledge to practical applications, but also facilitates the communication between scientists and engineers at a global level (Brdjanovic, 2015).

by knowledge transfer and capacity-building. In addition to North–South cooperation, South–South cooperation can further support developing countries in improving their scientific, technological and innovative capacity. The transfer of new technologies, where their application is feasible and affordable, should be equally promoted.

Emerging pollutants (see Box 4.1) represent an evident knowledge and research gap. Research is needed to improve the understanding of the dynamics of these pollutants in water resources and the environment, and the methods to remove these pollutants from wastewater (UNESCO, 2015). Improved techniques for the assessment, monitoring and removal of emerging pollutants are required, as is further research on the potential for multi-resistant pathogen development. There are also huge gaps in the existing regulatory and monitoring frameworks, as well as in data availability regarding the occurrence level of emerging pollutants in wastewater and receiving water bodies (UNESCO, 2015).

Another necessary element for research and capacity building is a new health risk assessment related to pathogens present in wastewater and the mitigation measures required in developing countries. The most common health risk assessments are based on models that were largely studied and verified in developed countries. Similar models and studies are required for developing countries as well. While health risk mitigation measures generally target pathogen-related threats, health risks related to chemical pollutants also require attention, especially due to the ineffective industrial wastewater management in developing and emerging countries.

It is also essential to understand how external factors like climate change will impact wastewater management. Research on the impacts of climate change on wastewater systems and treatment processes has only recently begun to appear (GWP, 2014) and many questions remain to be studied. Furthermore, more research efforts and innovative data collection and sharing tools are needed to address the enormous data gaps with regard to wastewater.

17.2.1 Barriers to research, innovation and technology applications

Lack of financing is a major barrier for the application of existing technologies in developing countries, but also for the promotion of research and the transitioning of new technologies for large-scale applications in developed countries. The high costs of high-end technologies hamper their widespread application, especially in developing countries. Furthermore, a limited market niche for new technology applications halters innovation (Daigger, 2011). The limited knowledge about the market for products recovered from wastewater adds to this challenge. Scarce data and information on wastewater form another major impediment to research and innovation, as is the (often-missing) link between the academia, industry and local government.

Translating innovation into practical application requires research into financing opportunities and into ways to create a market niche for new technologies, building human and technical capacities, and engaging stakeholders, including the private sector. This can be enabled through strong political will and government support (see Box 17.2).

BOX 17.2 IMPLEMENTATION OF CUTTING-EDGE TECHNOLOGIES IN WASTEWATER IN JAPAN

The Government of Japan is supporting innovation in the field of wastewater treatment and resource recovery through the B-DASH (Breakthrough by Dynamic Approach in Sewage High Technology) project, with the aim of implementing cutting-edge technologies by subsidizing innovations and standardizing their application. Under B-DASH, private companies in partnership with local governments can apply for subsidies for field-testing and implementing new technologies, including the construction of a facility. Results of this field-testing are used for the development of standardization guidelines, issued by the National Institute for Land and Infrastructure Management of Japan. In total, 31 new technologies have been adopted and brought into practice through the B-DASH project since its commencement in 2011, some of which have the potential to be applied globally in the near future.

For example, in 2012, two Japanese firms collaborated with the City Government of Osaka to test a new pipeline-based system for wastewater heat utilization at the Ebie Wastewater Treatment Plant. This new system can reduce CO_2 emissions from air-conditioning or hot-water supply by 15–25% compared to conventional technologies. In 2014, a new guideline for introducing a pipeline-based wastewater heat recovery system was issued, based on field-tested results. Moreover, in order to promote private sector investment in wastewater, the Sewage Act of Japan was amended in 2015 so that private companies can install wastewater heat exchangers inside sewers.

Contributed by Ministry of Land, Infrastructure, Transport and Tourism of Japan and Takahiro Konami (UNESCO-IHP).

17.3 Future trends in wastewater management

Whereas past innovation in the field of wastewater focused mainly on advanced treatment technologies, new and innovative solutions are emerging, combining both technological and management aspects.

Future trends in wastewater management increasingly focus on water reuse and resource recovery, which provide the additional benefits of safeguarding public health and reducing environmental pollution. For example, water reuse, the creation of commercial (phosphorus) fertilizers, and in particular energy recovery, can significantly lower operation and maintenance costs (Wichelns et al., 2015).

Innovative wastewater management solutions that incorporate interdisciplinary and integrated approaches are also becoming more common and an area of growing research interest. Decentralization at an appropriate level, combining centralized and decentralized solutions, is also appearing as a potential alternative, transitioning from oversized, centralized water and wastewater facilities, to infrastructure at a more adequate management scale (see Chapter 15).

17.3.1 Shifting from wastewater treatment to water reuse and resource recovery

The technological advances in wastewater treatment over the past decades have presented an opportunity to shift the primary objective of wastewater management from 'treat and dispose' to 'reuse, recycle, and recover resources'. Various technological options for resource recovery from wastewater and sludge exist at different stages of development and application, and are developing rapidly (see Chapter 16). Technological opportunities for resource recovery from wastewater are also creating a new niche with profitable business models, which facilitates the sustainability of the applied solutions (Strande et al., 2014; Otoo and Drechsel, 2015), although more research in resource recovery markets and economically sustainable revenue models is needed.

Trends in resource recovery move towards innovative management approaches, most notably integrated resource recovery, which in turn requires supportive regulations, market demand, investment, social acceptance and a willingness of different stakeholders to work together. It also requires a holistic view in order to ensure collective thinking among future practitioners, decision-makers and marketers (Holmgren et al., 2015).

Future wastewater treatment plants will be expected to deliver recovered resources and high-quality water for reuse in different sectors, while being cost-effective and self-sufficient in terms of energy.

17.3.2 Combining centralized and decentralized solutions at an appropriate scale

On the trajectory from on-site to off-site sanitation systems, recent innovations have shown that a mixed portfolio of solutions, including the combination of centralized and decentralized wastewater management facilities, can also be suitable to large service areas, while offering benefits of decentralization such as reduced investment, low operation and maintenance costs, and customizability to local conditions (Cairns-Smith et al., 2014).

BOX 17.3 DISTRIBUTED WASTEWATER SYSTEMS: AN ALTERNATIVE TO CENTRALIZED SYSTEMS

Distributed systems represent a flexible, localized and highly networked approach, where the central infrastructure plays an arterial role, while smaller, tailored systems operate and interact with users at a more localized level (Biggs et al., 2009). Distributed water systems are not merely technical innovations, but also require innovative governance and are not appropriate in every context. Even in those specific contexts where they are the most appropriate solution, distributed systems face several barriers that limit their diffusion (OECD, 2015b):

Firstly, distributed systems can weaken existing central systems (e.g. to collect and treat wastewater), when the best-off consumers disengage from the central network, depriving the managing utility from revenues. This is an issue, as distributed systems work best in combination with centrally piped infrastructures. Utilities and city administrations may be reluctant to explore options that negatively affect the revenue base of the existing networks, unless alternative sources of revenues are identified.

Secondly, distributed systems raise the issue of responsibility: who is responsible and accountable for the service provided at the building or district level? Accountability is an issue, as distributed systems require the capacity to monitor and control the quality of multiple water flows at several levels, which will also lead to additional costs.

Thirdly, the complexity of economies of scale in urban water management needs attention. Considering physical economies of scale, a large treatment plant is usually cheaper to operate than several smaller ones. However, system economies can counterbalance physical economies of scale, for example, by saving investment costs on centralized infrastructure expansion compared to on-site wastewater treatment and reuse technologies.

Source: OECD (2015b).

Contributed by Xavier Leflaive (Water Team Leader, OECD Environment Directorate).

A concept of 'distributed wastewater systems', which refers to a highly networked and localized approach to production, distribution and consumption, can be seen as an alternative based on the optimum combination of different centralized and decentralized systems for managing wastewater across networked cluster systems. This option is more efficient in terms of time, energy and costs, and generates positive externalities for end users and the environment. However, significant challenges can exist in terms of implementation (see Box 17.3).

Additional research is needed to better understand how to best combine systems in a portfolio of solutions (sewered and unsewered) across a variety of scales, in countries where wastewater infrastructure is only emerging (Cairns-Smith et al., 2014). Key research issues in this area include: cost-effectiveness, consumer behaviour, acceptance and incentives, business models and institutional arrangements. Furthermore, issues around the system ownership, household acceptance and financing of these systems, especially in developing countries, need to be considered.

17.4 Capacity building, public awareness and collaboration among stakeholders

Access to scientific knowledge, research, new technologies, appropriate education and training on sustainable solutions for wastewater management is not readily available in less developed countries.

Education and capacity building is vital and can be offered through training programmes focusing on different aspects of wastewater management in developing countries, both targeting water professionals and as part of formal educational curricula at different levels. This can directly influence issues of social perception and acceptance, especially in wastewater use and resource recovery.

The social dimension should not be underestimated. Safe water reuse, for example, requires active stakeholder participation, based on an understanding of benefits and risks. Public education campaigns can raise awareness among the general public about the ways in which water can and is being safely reused, even for drinking purposes, with provocative examples – like water reuse by astronauts on the International Space Station.

Enabling stakeholder involvement and capacity development as early as possible is critical for the success of planned reuse projects. Where reuse is based on a multi-barrier approach, behavioural change and the acceptance of best practices are keys to success. As stakeholders might lack the appropriate risk awareness and/or do not directly benefit from adopting safety measures, a better understanding of gender-specific incentives (both positive or negative) is needed to promote recommended practices, with the highest potential for local adoption (Karg and Drechsel, 2011).

Institutional capacity building is essential. If the entity in charge of operation and maintenance of wastewater facilities lacks the appropriate institutional capacity, the risk of failure will remain, regardless of whether the utility is managing smaller, decentralized or larger centralized plants (Murray and Drechsel, 2011). In this regard, a new generation of scientists, engineers and professionals, addressing different aspects of wastewater management, needs to be trained to face the problems that arise from increasingly complex and interconnected issues at different scales. Future wastewater managers will require a mix of technical and managerial skills in order to develop and implement a compendium of solutions across the various wastewater flows, from pollution abatement at the source through collection and treatment to water reuse and the recovery of useful by-products.

Concrete efforts are required to train female researchers in the field of wastewater, in order to promote a greater number of women scientists in the higher echelons of scientific institutions and decision-making in developed and developing countries alike (WWAP, 2016). There is an urgent need, both in developed and developing countries, for education at all levels – from informal education for children and adults to higher education curriculum development – on the values of wastewater, while the risks of wastewater mismanagement for human and environmental health need urgent attention.

The development and implementation of innovative, transdisciplinary and holistic educational and training approaches, including actualized, distance, student-catered, problem-based learning and training materials, are essential to ensure that the issues and challenges can be embraced with deeper insight, advanced knowledge and greater confidence.

CHAPTER 18

WWAP | Richard Connor, Angela Renata Cordeiro Ortigara, Engin Koncagül and Stefan Uhlenbrook

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CREATING AN ENABLING ENVIRONMENT

Ellerntors Bridge in Hamburg (Germany)

In conclusion, this chapter presents a roadmap of potential responses, solution options and means of implementation that can be adopted to foster progress in improving wastewater management. Such options go well beyond the merely technical to include legal and institutional frameworks, financing opportunities, building knowledge and capacity, mitigating human and environmental health risk, and fostering social acceptance. As the challenges vary from place to place around the world, it is incumbent upon stakeholders and decision-makers in each region, country, basin and community to identify the most appropriate mix of options for their particular situation.

Addressing the world's wastewater-related challenges is crucial to advancing human health and livelihoods, promoting the growth of local and national economies, improving the quality of water, air and land, and protecting and enhancing ecosystems and the services they provide. Indeed, improved wastewater management represents a critical factor in achieving sustainable development for all. Nonetheless, as described throughout this report, wastewater is not merely a problem in search of solutions, but a valuable resource that, if properly managed, can provide tremendous opportunities and benefits.

The demand for – and use of – water is increasing in most parts of the world as a result of population growth, urbanization and improving socio-economic conditions. At the same time, water availability is increasingly compromised by climate change, unsustainable groundwater abstraction and pollution. In several areas, from the western USA and southern Europe through Northern Africa and the Middle East to parts of China and India, freshwater resources are already severely stressed and service providers are struggling to meet the ever-increasing demand for freshwater. Reusing water enhances freshwater availability for meeting human and environmental needs and is indeed already happening in several places. Depending on its level of treatment, wastewater can be – and is being – used for multiple purposes, ranging from irrigation and landscaping to industrial uses, and even as a source of potable drinking water.

More water use also means more wastewater. And, with so much of the world's wastewater being released untreated, the impacts on human health and the environment have been increasing proportionately.

Appropriately treating wastewater prior to its release reduces the pollution loads to the environment and lowers health risks to humans. Some of the more advanced treatment processes may appear financially cost-prohibitive, especially for the poorest communities. However, when compared with the cost of building a new dam, desalination or importing water from another basin, and when health and environmental benefits are taken into consideration, improved wastewater management makes sound economic sense, particularly under conditions of water scarcity. Improved wastewater management can also lead to the creation of direct and indirect jobs in water-dependent sectors and beyond (WWAP, 2016).

There are basically two approaches to addressing the challenges related to pollution from wastewater. The first involves preventing excessive use (quantity) and contamination of water at the point of initial use, thus reducing the overall volume of wastewater produced and the pollution loads it contains. The second involves the collection of wastewater and applying appropriate levels of treatment (i.e. 'end-of-pipe' solutions) for other uses or discharge into the environment. This approach includes setting quality standards and regulations for incoming wastewater streams and outgoing treated wastewater. Where prevention and appropriate treatment are impracticable, cost-effective solutions are available to reduce risks from exposure to untreated wastewater (see for example WHO, 2006a).

Planning for water reuse has been gaining momentum in the context of sustainable water resources management, the greening of economies, and urban planning (cf. Lazarova et al., 2013). However, water is not the only resource that can be recovered from wastewater. Nutrients, organic matter, energy and other useful by-products can also be extracted from certain types of wastewater. For example, the cost-efficiency of energy (biogas) recovery from sewage sludge is well-documented (cf. WWAP, 2014; UN-Water, 2015a). Recovering water and useful by-products is critical to balancing economic development with environmental and resource protection in a circular economy.

The wastewater management cycle encompasses four essential steps:

1. reducing and preventing pollution at the source;
2. removing contaminants from wastewater streams (i.e. treatment);

3. using treated wastewater for various applications; and

4. recovering useful by-products.

Each of these can been seen as a different but interconnected step in a logical process, or ladder approach, within the broader IWMI framework. As such, a number of technical, regulatory and financial considerations need to be taken into account in order to improve wastewater management and maximize its opportunities and benefits.

Water scarcity has been moving up on the global political agenda, including the 2030 Agenda for Sustainable Development. The SDGs included in the Agenda also promote improved water quality through enhanced wastewater management (UNGA, 2015a). Indeed, the integrity and biological diversity of ecosystems have been increasingly impacted by wastewater, which has compromised ecosystem services upon which sustainable development – in all its economic, social and environmental dimensions – depends.

Given wastewater's potential role in addressing water scarcity, pollution and resource recovery, it is not surprising that wastewater management is attracting increasing attention. Moreover, with so little wastewater being treated and even less being used, the potential opportunities from exploiting appropriately treated wastewater as a resource are enormous. The following sections describe a number of responses that collectively would create an enabling environment for enhancing water reuse and the recovery of useful by-products.

18.1 Technical options

Despite the increasing number of cases of water reuse for agricultural, industrial, environmental and recreational purposes as well as for drinking water, the potential for using 'fit-for-purpose' treated wastewater is yet to be fully exploited, particularly in developing countries and emerging economies. Whereas high-income countries treat about 70% of the wastewater they produce, lower middle-income and low-income countries, respectively, only treat an estimated 28% and 8% of their wastewater (Sato et al., 2013).

The choice of technologies is highly site-specific. Wastewater is managed in a large diversity of climatic systems, with varying degrees of water resources availability, levels of economic development, types of economic activity and settlement patterns, all of which result in different challenges for wastewater and water quality management (UNEP, 2015a). In spite of existing knowledge gaps, a wide range of technical solutions have been developed, and it is most often a question of choosing and implementing the right technologies at the right place, in a way that optimizes the most suitable mix of both grey and green infrastructure.

For developing countries, appropriate, effective and low-cost wastewater treatment technologies are available (see Chapter 15). Preliminary, primary and secondary treatment can be simple processes that produce effluent of the quality required for a variety of uses, with low investment costs and, in particular, low operational and maintenance costs (Jiménez-Cisneros, 2011; Libhaber and Orozco-Jaramillo, 2012), particularly when combined with well-managed green infrastructure (see Chapter 8). As biological processes perform better at higher temperatures, many of these processes are particularly well-suited to countries with warm climates, which includes most developing countries (Qadir et al., 2015b). Their objective will be to incrementally increase the levels of wastewater treatment from preliminary, primary and secondary treatment towards tertiary treatment processes, thus generating effluent of increasing quality.

Choosing the most appropriate type of wastewater treatment system is also important. While there is no one common solution, low-cost DEWATS are gaining in acceptance and are increasingly being used in developed and developing countries alike (see Chapter 15). For developing countries in particular, it has been suggested that centralized, cutting-edge treatment plants are a risky investment due to insufficient institutional capacity and financing. Appropriate technologies relying on simple processes with lower capital and operational and maintenance costs are generally more sustainable, while potentially offering effluent of adequate quality levels for several potential uses, including agriculture (Libhaber and Orozco-Jaramillo, 2012). It has been estimated that the investment costs for such simple or 'appropriate' treatment facilities represent only 20–50% of conventional treatment plants, with even lower operation and maintenance costs (in the range of 5–25% of conventional activated sludge treatment plants) (Wichelns et al., 2015).

Although developed countries generally have advanced wastewater management systems in place, they too face a number of challenges, including ageing infrastructure that is often inappropriately suited for dealing with current wastewater loads (see Chapter 12), staff attrition (WWAP, 2016) and growing concern over emerging pollutants (see Chapters 4 and 17).

The concept of 'fit-for-purpose' is another critical consideration. As it is unlikely that the capacity for advanced wastewater treatment in developing countries will increase substantially in the near future, it will be important to develop and adopt tailored technologies that treat wastewater to levels appropriate for selected end uses. Irrigated agriculture has historically been the most common use for partially treated wastewater, and its use for this purpose has been reported in around 50 countries, on 10% of all irrigated land (FAO, 2010). Other opportunities for using treated wastewater also exist – from urban landscaping to potable water, each requiring different levels of treatment. Integrating these potential uses into the wastewater management systems (via 'fit-for-purpose' treatment) is required to unleash the sizeable potential of water reuse (see Chapter 16).

Finally, technologies for the recovery of useful by-products from wastewater, such as energy (heat and biogas) and nutrients, have been evolving rapidly and are increasingly cost-effective, especially when considered within the overall wastewater management cycle (see Chapter 16). For example, thermal, chemical and hydraulic energy contained in wastewater can be recovered in the form of biogas, heating/cooling or electricity through either on-site or off-site processes (Meda et al., 2012), and various technologies exist for on-site energy recovery through sludge/biosolids treatment processes integrated into wastewater treatment plants. New methods are also available for recovering phosphorus from wastewater and for transforming septage into fertilizer at low cost. Technological innovations in these fields will play a critical role in advancing resource recovery and reuse, especially in developing countries and emerging markets (Hanjra et al., 2015a).

18.2 Legal and institutional frameworks

One of the main reasons why wastewater has been largely neglected is that it often lacks an institutional home, and many reformed water utilities have not realized the value in investing in wastewater infrastructure (UN-Water, 2015a). Improving wastewater governance therefore requires the alignment of varying interests in ways that allow people and organizations to collaborate towards meeting basic common needs while maximizing benefits across the various stages of wastewater management (see Chapter 3).

Regulatory frameworks need to be appropriate to time and place, recognizing the diversity of economies and cultures and the very different needs of different parts of society (UNEP, 2015b). Although there is a need to raise standards for water quality nearly everywhere, achieving progress will require a flexible and incremental approach. Adequate regulation is time-consuming and expensive, but if the whole-life costs and benefits of managing wastewater are factored in, the savings for society, the environment and the economy can be substantial (UNEP, 2015a). An effective regulatory framework requires that the implementing authority has the necessary technical and managerial capacity and performs in an independent fashion, with sufficient powers to enforce rules and guidelines. Transparency and access to information motivates compliance by promoting trust among users with respect to the implementation and enforcement processes (UN-Water, 2015b).

Wastewater management is of international concern, as pollution problems have no borders. The importance of international collaboration is illustrated by the case of the Danube and the Black Sea (see Box 3.1). Adequate national and international coordination can help ensure that limited financial resources are spent in the most effective way.

However, actions to address water pollution – by cleaner production and consumption processes and more efficient and comprehensive treatment – are nearly always undertaken locally. Hence, local regulation, stakeholder consultation and motivation for compliance remain critical elements of any sustainable wastewater management strategy.

Policies and regulatory instruments are also implemented locally and need to be adapted to varied circumstances. For example, where economic inequalities are stark, one centralized service provision strategy is unlikely to serve all users. It is therefore important that the political, institutional and financial support be distributed equally, as 'bottom-up' initiatives and small-scale local (i.e. decentralized) provision of wastewater management services also need the support and enabling environments to thrive.

Likewise, the ways of treating and using wastewater need to be chosen according to local circumstances, taking into account ecosystem needs, competing uses of water and culturally acceptable practices. Within such constraints, water can – and needs to – be reused as intensively as possible as a response to water scarcity and the increasing demand for food and energy. Where high-quality effluent is required, the adoption of (or changes in) water reuse legislation has been shown to be the main 'push factor' that influenced treatment plants in changing their current technology by essentially forcing them to implement advanced treatment schemes (DEMOWARE, 2016).

In many countries, new legislation and institutional arrangements will be required to accommodate and regulate the use of wastewater for a variety of uses, ranging from irrigation and industrial water recycling to aquifer recharge and the enhancement of ecosystem services. As an additional source of water, treated wastewater can be integrated into national water supply schemes (Hanjra et al., 2015b).

New regulations regarding the recovery of wastewater by-products are also required. Although the technical expertise is available (see Chapter 16), there is often little or no legislation on quality standards for these products, creating market uncertainties that can discourage investment. Markets for these products could be stimulated by financial or legal incentives (e.g. compulsory blending of recovered phosphates in artificial fertilizer). Applying quality criteria to the end product, rather than to the input material, could also help promote market acceptance of high-quality materials from municipal wastewater and further stimulate the recycling of nutrients and other by-products of wastewater as a critical part of the circular economy.

The management of wastewater and the consequent protection of water resources is an area where societies' ability to act for the benefit of those without a political voice of their own – the vulnerable, the coming generations and ecosystems – is continually challenged. Where the enforcement of standards and permits is required, the impartiality of public authorities is crucial. Transparency and public participation in policy-making may be ways to assure sensible, acceptable and sustainable solutions. A common vision and generalized agreement on the goals of wastewater management is the best guarantor of their successful implementation.

18.3 Financing opportunities

Wastewater management and sanitation are generally considered to be expensive and capital-intensive (see Section 3.3). This is especially the case of large centralized systems, which require a large degree of up-front capital expenditure. Once completed, these systems also rarely generate significant revenue and are therefore unable to cover their own operation and maintenance costs over the medium and long term, which leads to their rapid deterioration. Therefore, it is unsurprising that investing in wastewater management and water quality has not been considered a political priority in many developed and developing economies. The problem is further exacerbated by chronically lacking investment in the development of institutions and human capacity (see Chapter 17). It is essential to coordinate investments and financing in order to improve the overall performance of wastewater management systems (WHO, 2015). A results-based approach to financing can also help promote the optimal design and efficient implementation and operation of these systems (WWC/OECD, 2015).

Decentralized wastewater treatment systems (DEWATS) can be used to offset some financial problems generated by centralized systems (see Section 15.4). Their use is most common in smaller communities, treating lower volumes of wastewater and often applying low-cost technologies (e.g. stabilizing ponds, anaerobic filters and constructed wetlands). When properly designed and implemented, such low-cost technologies can provide satisfactory results in terms of effluent quality. However, even though the initial investments for these technologies are low, they still require an appropriate level of operation and maintenance in order to avoid system failure. Therefore, financial resources and investments in human capacity need to be considered early in the design phase to ensure the proper functioning of decentralized systems over the long term.

In order to maximize the net benefits of wastewater treatment systems, it is also important to examine their social, environmental and financial costs and benefits locally and downstream, and to compare these results to the next-best alternative, including the costs of no action over the longer term. Indeed, the vast majority of available evidence suggests that the costs of inadequate investment in wastewater management are far greater than in terms of actual money spent, particularly when the direct and indirect damages to health, socio-economic development and the environment are taken into consideration (see Section 13.5) (UN-Water, 2015a).

Wastewater use can add a new revenue stream to wastewater treatment, particularly under conditions of recurring or chronic water scarcity. Several different business models have been implemented where cost and value recovery offer a significant advantage from a financial perspective (see Section 16.3). However, revenues from the sale of treated wastewater are not generally adequate to cover the operational and maintenance costs of the water treatment facility itself. When different entities are responsible for different parts of the sanitation service chain, clearly agreed cost-, risk- and benefit-sharing mechanisms need to be in place (e.g. public–private partnerships or other participatory approaches) if the value created through reuse is to help maintain the sanitation service chain (Wichelns et al., 2015). Within the broader context of water resources management, multi-purpose water infrastructure may offer additional advantages for enhanced wastewater treatment, but this is often more difficult to finance than single-purpose projects (WWC/OECD, 2015).

Even when delivered to the tap, potable water remains generally undervalued and underpriced when compared to the actual cost of the service. Treated wastewater must itself be priced lower than potable water in order to gain public acceptance. In such cases, encouraging water reuse takes precedence over cost recovery. Yet, even where revenues from wastewater use fail to cover their extra costs, investments in water reuse generally compare well to the costs of dams, desalination, inter-basin transfers and other options to increase water supplies (Wichelns et al., 2015).

The recovery of nutrients (mainly phosphorus and nitrogen) and energy can add significant new value streams to improve the proposition of cost recovery. In recent years, several technological innovations have emerged that allow for increased efficiency in the recovery of nutrients and energy (see Section 16.2). Studies on multiple-resource recovery show that greater financial benefits become possible when the resource reuse trajectory extends not only to energy, but also targets carbon credits (Hanjra et al., 2015b). Recovered biogas has successfully been used as an energy source for the treatment plant itself, in combined heat and power generation (CHP), or cogeneration, and even as transportation fuel (WWAP, 2014). Reintroducing recovered phosphorus and nitrogen as fertilizer would drop the price of these products and contribute to lowering the overall cost of food (Sengupta et al., 2015). Methods are now available for recovering phosphorus from wastewater and for transforming septage into pelletized fertilizer at low cost (Hanjra et al., 2015a). Furthermore, the controlled recovery of phosphorus – a non-renewable resource indispensable as a fertilizer in modernized agriculture – can be more financially advantageous than the chemical treatment needed to remove unwanted phosphorus precipitation at the treatment plant. Phosphorus recovery will likely become even more cost-competitive with the rising cost of mining finite rock-phosphate (Wichelns et al., 2015). Apart from tangible economic benefits, improved nitrogen recovery would also reduce the nitrogen loading to the atmosphere (Sengupta et al., 2015). Although still in early stages of development, innovative technologies for recovering other valuable materials are also emerging, such as metal recovery via bioelectrochemical processes (Wang and Ren, 2014).

In summary, the financing of wastewater treatment and use becomes increasingly favourable when treatment costs are low and the value proposition goes beyond recovering water from wastewater to include the recovery of nutrients, energy and other useful by-products. In view of these potential synergies across the wastewater management cycle, it has been demonstrated that public–private partnerships, based on cost recovery across the entire wastewater management cycle, can help incentivize and even co-finance the sanitation/wastewater sector, while at the same time promoting small- and medium-scale entrepreneurs (Murray et al., 2011). The availability of end users who can absorb the supply of product and are willing and able to pay for it (i.e. the market) represents the most critical condition for implementing any given water reuse and by-product recovery and use scheme (Rao et al., 2015).

18.4 Enhancing knowledge and building capacity

Data and information on wastewater generation, treatment and use is essential for policy-makers, researchers, practitioners and public institutions in order to develop national and local action plans aimed at environmental protection and the safe and productive use of wastewater. However, there is a pervasive lack of data relating to virtually all aspects of water quality and wastewater management, particularly in developing countries (UN-Water, 2015a). When available, country-level data on wastewater generation, treatment and use are often incomplete or outdated (Sato et al., 2013), so that direct comparisons between countries can be difficult or impossible (see Section 4.4). The monitoring required for measuring progress towards SDG Target 6.3 can be expected to generate some progress in national-level monitoring and reporting (see Chapter 2).

Knowledge concerning the volumes and, perhaps even more importantly, the constituents of wastewater are necessary tools for protecting human and environmental health and safety. Here too, there is much room for improvement at the basin and local level in order to monitor the effectiveness of regulatory systems and support the enforcement of environmental laws.

In order to enhance wastewater management, it is equally essential to ensure that the appropriate levels of human capacity are in place (see Chapter 17). Therefore, continuous professional development throughout all levels is needed to keep up with the ever-evolving technology and societal needs.

There is always a need for appropriately trained staff, irrespective of whether it is concerning large-scale centralized wastewater management systems or smaller, on-site systems. For example, the operation and maintenance of many on-site systems has often been left to homeowners or local authorities, leading to system failure due to lack of, or improper, maintenance (UN-Water, 2015a). According to the International Water Association, "many developing economies are lacking significant numbers of water professionals, and the necessary knowledge, experience and specialist skills to meet the rising demand for water and sanitation services" (IWA, 2014, p. 3). Investing in adequate training also makes the difference between good regulatory policies and actually controlling water quality- and harvesting-related benefits (UN-Water, 2015b). As stated in the 2016 United Nations World Water Development Report, "critical relationships and essential linkages exist between the management of water [in its broadest sense] and employment opportunities in countries at all levels of development. […] Water plays a key role in generating and sustaining direct employment opportunities across a large array of sectors and in unlocking the potential for indirect employment creation through its multiplier effect" (WWAP, 2016, pp. 7 and 126).

Organizational and institutional capacities in the wastewater management sector are also inadequate, particularly in developing countries. Given that wastewater management often lacks an 'institutional home', the challenges involved in aligning varying interests and increasing collaboration towards meeting basic common objectives call for strong efficient and transparent institutions, capable of both designing guidelines and enforcing regulations.

Finally, research and development are needed to adapt innovative technologies to local contexts, both in terms of improved low-cost wastewater treatment systems (including the separation of waste streams to tailor treatment and the next intended use), as well as increased efficiencies in the use of treated wastewater and recovered by-products (see Chapter 17). It is also increasingly important to improve the processes for the recovery of metals and emerging pollutants, which usually require high-capital and high-capacity technologies. More research is needed on the impacts and potential removal of emerging pollutants such as microbeads (see Box 4.2) and potentially hazardous pharmaceutical chemicals such as endocrine disruptors and antimicrobial resistance-enhancing compounds.

18.5 Mitigating human and environmental health risks

The discharge of untreated wastewater can have severe impacts on human and environmental health, including outbreaks of food-, water- and vector-borne diseases, as well as pollution and the loss of biological diversity and ecosystem services. Unfortunately, in spite of the growing efforts to increase treatment and coverage levels, much of the wastewater generated in cities and rural areas will remain untreated or only partially treated for many years to come. As a result, the largely unintentional and informal use of untreated or partially treated wastewater for irrigation and other uses is likely to continue. Risk management is therefore essential for enhancing the safety of wastewater use.

The most appropriate option for managing risks from wastewater use in a given context will vary according to the intended end use, sociocultural acceptance, and economic, institutional, biophysical and technological factors (Balkema et al., 2002). Whenever human exposure is considered likely (e.g. via food or direct contact), more rigorous risk management measures will be required. For example, less stringent management measures would be applied where wastewater is used for the irrigation of non-food crops, in comparison to landscape irrigation at a public park or school, where direct contact with exposed contaminants is more likely. Even more stringent measures are required when wastewater is used to augment potable supplies (Keraita et al., 2015).

The *WHO Guidelines for the Safe Use of Wastewater, Greywater and Excreta in Agriculture* (see Section 7.2.2) proposes a multi-barrier approach in which wastewater treatment is just one of several options to protect public health (WHO, 2006a). When untreated wastewater is used for the irrigation of comestible crops, for barriers at wastewater sources, on farms, at markets and at the consumer level, thus providing protection at different points along the production chain.

18.6 Fostering social acceptance

Even if wastewater use projects are technically well-designed, appear financially realizable and have incorporated appropriate health protection measures, water reuse schemes can still fail, if planners do not adequately account for the dynamics of social acceptance (see Sections 3.4 and 16.6). Overall acceptance of (safe) wastewater use varies with the development stage of a society and can be a dynamic process, which makes social feasibility studies, close participation of user groups, and trust building critical components of a successful wastewater use programme (Drechsel et al., 2015b). While water scarcity can promote a positive perception of wastewater use, other factors will impact its public acceptance, including the availability of alternative water sources, levels of education, perceptions of health risks, religious concerns and the means and messages used in knowledge sharing and communication. Overcoming negative public perceptions is particularly critical in the case of drinking water (i.e. potable water reuse). Although these systems often present higher water quality standards than other water sources, extensive information campaigns and participation by the public are required to build trust in the system and overcome the so-called ‘yuck’ factor.

The health risks associated with water reuse need to be assessed, managed, monitored and reported on a regular basis in order to gain public acceptance and to maximize the benefits of using wastewater while minimizing the negative impacts (UN-Water, 2015a). In low- to middle-income countries with limited treatment capacity, where untreated or partially treated wastewater is released into water bodies and then abstracted and used for informal irrigation, the cultural and social challenge is not the introduction of water reuse but the prevention of unintentional/ unsafe use of untreated wastewater. In those cases, support is needed for a transition towards safe reuse of wastewater (Drechsel et al., 2015b).

18.7 Coda

In a world where demands for freshwater are continuously growing, and where limited water resources are increasingly stressed by over-abstraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable.

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ANNEX 1 *LEXICON*

There can be different, even inconsistent definitions available for terms relating to wastewater. The following definitions have been adapted from a number of published works in order to provide a common understanding and to ensure consistency across the terminology used in the WWDR 2017.

Agricultural runoff: Water from agricultural fields that does not infiltrate into the soil and runs off as overland flow.

Biosolids: Sewage sludge adequately treated, processed and applied as fertilizer to improve and maintain productive soils and stimulate plant growth.

Blackwater: Wastewater generated from the toilet, collected separately from a sewage flow. It contains urine, faeces, flushwater and/or toilet paper.

Centralized wastewater treatment system: Managed system consisting of collection sewers and a single treatment plant used to collect and treat wastewater from a specific service area.

Circular economy: An economy which balances economic development with environmental and resource protection. It places emphasis on the most efficient use and recycling of resources, and environmental protection. A circular economy features low consumption of energy and other resources, low emission of pollutants, minimum waste production and high efficiency. It involves applying cleaner production in companies, as well as eco-industrial park development and integrated resource-based planning for development in industry, agriculture and urban areas.

Contaminant: Biological, physical, chemical, or radiological substance which has an adverse effect on water, soil or air. The presence of contaminants does not necessarily mean that the water poses health risks.

Combined sewer system: Sewer systems designed to collect both municipal wastewater (from domestic, industrial and other sources) and urban runoff, and transport it to the wastewater treatment plant (or alternative means of disposal).

Decentralized wastewater treatment system: System used to collect, treat, and disperse or reclaim wastewater from a small community or service area.

Domestic wastewater: Composed of blackwater, greywater and potentially other types of wastewater deriving from household activities in residential settlements.

Emerging pollutants: Any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects.

Endocrine-disrupting compounds (EDCs): Natural or synthetic compounds that interfere with the synthesis, secretion, transport, binding, action, or elimination of natural hormones of living organisms that are responsible for the maintenance of homeostasis, reproduction, development and/or behaviour.

Endocrine system: The collection of human glands that produce hormones that regulate metabolism, growth and development, tissue function, reproduction, mood, sleep, and/or other physiological functions.

Eutrophication: Process by which a body of water becomes enriched in dissolved nutrients (e.g. nitrogen and phosphorus) that stimulate the growth of aquatic plant life, usually resulting in the depletion of dissolved oxygen.

Greywater: Wastewater generated from a washing machine, bathtub, shower or bathroom sink, collected separately from a sewage flow. It does not include wastewater from a toilet.

Heat pollution: The warmer-than-ambient water released from industrial systems (i.e. cooling in thermal power plants), altering the temperature of the receiving water body in such a way that it impacts the local environment.

Heavy metal pollution: Pollution by metals with a high atomic mass deriving from a number of sources, such as industrial effluents.

Industrial wastewater: Water discharged after being used in, or produced by, industrial or energy production processes.

Micropollutants: Pollutants that are present in low concentrations in water (i.e. micrograms/litre or even less), such as pharmaceuticals, ingredients of household chemicals, chemicals used in small businesses or industries, environmental persistent pharmaceutical pollutants (EPPP), pesticides or hormones.

Municipal wastewater: Wastewater originating from domestic, industrial, commercial and institutional sources within a given human settlement or community. The composition of municipal wastewater can vary considerably, reflecting the range of contaminants released by the different combination of sources.

Nonpoint source pollution or diffuse pollution: Pollution resulting from land runoff, precipitation, atmospheric deposition or land drainage.

On-site wastewater treatment system: System relying on natural processes and/or mechanical components to collect, treat and disperse or reclaim wastewater from a specific location.

Pathogens or pathogenic microorganisms (e.g. bacteria, viruses, parasites or fungi): Microorganisms that can cause disease in humans.

Persistent organic pollutants (POPs): Toxic chemicals that adversely affect human health and the environment, including PCBs, DDT, and dioxins. POPs remain intact in the environment for exceptionally long periods of time and potentially bio-accumulate in the fatty tissues of living organisms.

Point source pollution: Point source pollution: any discernible and confined conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, fissure, container, intensive livestock operation, or vessel or other floating craft, from which pollutants are discharged. This term does not include diffuse urban stormwater discharges and return flows from agriculture.

Pollution: The result of substances/contaminants entering water bodies and thereby degrading the quality of water. Water pollution can have natural causes due to environmental causes (i.e. arsenic) or by anthropogenic activities.

Recycled water: Treated ('fit-for-purpose') wastewater that can be used under controlled conditions for beneficial purposes within the same establishment or industry.

Reclaimed water: Treated ('fit-for-purpose') wastewater that can be used under controlled conditions for beneficial purposes, such as irrigation.

Sediment pollution: Minerals, sand, and silt eroded from the land and washed into the water, potentially creating problems for aquatic organisms.

Septage: The nutrient-rich by-product of domestic wastewater after pre-treatment that accumulates in a septic tank or (less commonly) a pit latrine.

Sewage: Wastewater and excrement (blackwater) conveyed in sewers.

Sewerage: Pipes, pumps and other appurtenances or infrastructure for collecting and transporting the sewage from its points of generation to desired endpoints (i.e. treatment plant).

Sludge: The nutrient-rich organic materials resulting from the treatment of domestic sewage in a wastewater treatment facility.

Urban runoff: Surface runoff of rainwater and other forms of precipitation (i.e. snowmelt) in urban areas, where much of the land surface is covered by pavements, buildings and compacted landscapes that do not allow water to infiltrate in the soil, thus increasing the runoff volume. This runoff is a major source of urban flooding and water pollution in urban communities.

Urban wastewater: Includes both municipal wastewater and urban runoff, thus potentially containing a wide range of contaminants.

Wastewater or effluent: A combination of one or more of: domestic effluent consisting of blackwater and greywater; water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban runoff; and agricultural, horticultural and aquaculture runoff.[13]

Wastewater by-products: Materials (e.g. nutrients, metals) and energy that can be recovered from wastewater and used.

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[13] Even though urban and agricultural runoff may not be considered wastewater under certain definitions (e.g., when wastewater is understood as "water after it has gone through any use"), it is being considered as a form of wastewater for the purposes of this report, in part because of its direct relationship to the achievement of SDG 6.3 which states "improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials (…)".

Wastewater management: Includes the prevention or reduction of pollution at the source (in terms of the pollution load and the volume of wastewater produced), the collection and removal of contaminant from wastewater streams (i.e. treatment), and the beneficial use and/or disposal of treated wastewater and its by-products.[14]

Wastewater nutrients: This expression mainly refers to the presence of nitrogen and phosphorus in domestic wastewater, agricultural runoff (including from livestock and food processing) and in some industrial effluents. Nutrients can cause an excessive growth of algae (i.e. eutrophication) in water bodies, but they are also a recoverable wastewater by-product for agriculture and aquaculture.

Wastewater treatment: A process, or sequence of processes, that removes contaminants from wastewater so that it can be either safely used again (fit-for-purpose treatment) or returned to the water cycle with minimal environmental impacts. There are several levels of water treatment, the choice of which is dependent on the type of contaminants, the pollution load, and the anticipated end use of the effluent.

Preliminary treatment: Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems during the treatment operations and processes.

Primary treatment: Removal of a portion of the suspended solids and organic matter from the wastewater, which can or cannot include a chemical step or filtration.

Secondary treatment: Removal of biodegradable organic matter (in solution or suspension), suspended solids, and nutrients (nitrogen, phosphorus, or both).

Tertiary treatment: Removal of residual suspended solids (after secondary treatment), further nutrient removal and disinfection.

Quaternary treatment: Techniques for the elimination of micropollutants that may not have been removed by conventional treatment processes (primary, secondary and tertiary treatment).

Water reuse/wastewater use: Use of untreated, partially treated or treated wastewater.

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[14] Grammatically speaking, water is 'reused' and wastewater is 'used', but wastewater is not 'reused'.

ABBREVIATIONS and ACRONYMS

BAT	Best available technologies
B-DASH	Breakthrough by dynamic approach in sewage high technology
BOD	Biochemical oxygen demand
CBD	Central business district
CEF	Credit enhancement facility
CHP	Combined heat and power
CIP	Clean-in-place
COD	Chemical oxygen demand
CReW	Caribbean Regional Fund for Wastewater Management
CSOs	Combined sewer overflows
CWSRF	Clean Water State Revolving Fund
DEWATS	Decentralized wastewater treatment system
DPR	Direct potable reuse
EcoSan	Ecological sanitation
EDCs	Endocrine-disrupting compounds
EECCA	Eastern Europe, Caucasus and Central Asia
ESTs	Environmentally sound technologies
EU	European Union
FC	Faecal coliform bacteria
FAO	Food and Agriculture Organization of the United Nations
FSM	Faecal sludge management
GCC	Gulf Cooperation Countries
GEF	Global Environment Facility
GHG	Greenhouse gas
GI	Green infrastructure
IPR	Indirect potable reuse
IWRM	Integrated water resources management
LCA	Life cycle assessments
MBR	Membrane bioreactor
MDG	Millennium Development Goals
MENA	Middle East and Northern Africa
MW	Megawatt
NGO	Non-governmental organization

OECD	Organisation for Economic Co-Operation and Development
p.e.	Population equivalent
PCBs	Polychlorinated biphenyls
POPs	Persistent organic pollutants
PRTRs	Pollutant Release and Transfer Registries
PUB	Singapore Public Utilities Board
RECP	Resource-efficient and cleaner production
SADC	Southern African Development Community
SDG	Sustainable Development Goal
SEEA-Water	System of Environmental-Economic Accounting for Water
SFPUC	San Francisco Public Utilities Commission
SMEs	Small- and medium-sized enterprises
SS	Suspended Solids
SUDS	Sustainable urban drainage systems
TN	Total Nitrogen
TP	Total Phosphorus
TrackFin	Tracking financing to sanitation, hygiene and drinking water
TSS	Total suspended solids
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNGA	United Nations General Assembly
UN-Habitat	United Nations Human Settlement Programme
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
UNSD	United Nations Statistical Division
US EPA	United States Environment Protection Agency
UWWTD	EU Urban Wastewater Treatment Directive
WEF	World Economic Forum
WHO	World Health Organization
WSS	Water supply and sanitation
ZLD	Zero liquid discharge

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BOXES

FIGURES

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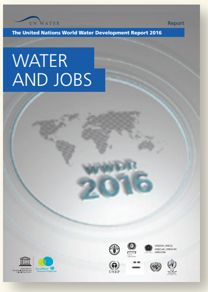

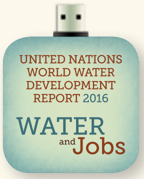

ISBN 978-92-3-100146-8
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166 pages
Price: EUR 45.00

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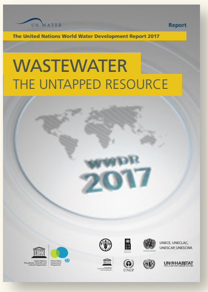

ISBN 978-92-3-100201-4
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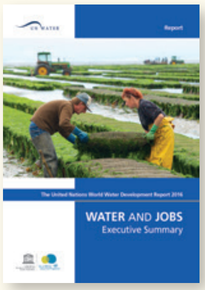

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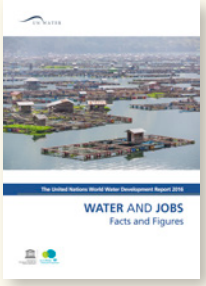

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United Nations
Educational, Scientific and
Cultural Organization

World Water
Assessment
Programme

UN-WATER REPORTS

UN-Water is the United Nations (UN) inter-agency coordination mechanism for freshwater-related issues, including sanitation. It was formally established in 2003 building on a long history of collaboration in the UN family. UN-Water is comprised of UN entities with a focus on, or interest in, water-related issues as Members and other non-UN international organizations as Partners.

The main purpose of UN-Water is to complement and add value to existing programmes and projects by facilitating synergies and joint efforts, so as to maximize system-wide coordinated action and coherence. By doing so, UN-Water seeks to increase the effectiveness of the support provided to Member States in their efforts towards achieving international agreements on water.

PERIODIC REPORTS

World Water Development Report (WWDR)

is the reference publication of the UN system on the status of the freshwater resource. The Report is the result of the strong collaboration among UN-Water Members and Partners and it represents the coherent and integrated response of the UN system to freshwater-related issues and emerging challenges. The report production coordinated by the World Water Assessment Programme and the theme is harmonized with the theme of World Water Day (22 March). From 2003 to 2012, the WWDR was released every three years. Since 2014, the Report is published annually to provide the most up-to-date and factual information of how water-related challenges are addressed around the world.

- ✓ Strategic outlook
- ✓ State, uses and management of water resources
- ✓ Global
- ✓ Regional assessments
- ✓ Triennial (2003-2012)
- ✓ Annual (since 2014)
- ✓ Links to the theme of World Water Day (22 March)

UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS)

is produced by the World Health Organization (WHO) on behalf of UN-Water. It provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking water. It is a substantive input into the activities of Sanitation and Water for All (SWA).

- ✓ Strategic outlook
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional assessments
- ✓ Biennial (since 2008)

The progress report of the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP)

is affiliated with UN-Water and presents the results of the global monitoring of progress towards access to safe drinking water, and adequate sanitation and hygiene. Monitoring draws on the findings of household surveys and censuses usually supported by national statistics bureaus in accordance with international criteria and increasingly draws on national administrative and regulatory datasets.

- ✓ Status and trends
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional and national assessments
- ✓ Biennial (1990-2012)
- ✓ Annual updates (since 2013)

UN-WATER PLANNED PUBLICATIONS 2018

- Update of UN-Water Policy Brief on Water and Climate Change
- UN-Water Policy Brief on the Water Conventions
- UN-Water Analytical Brief on Water Efficiency
- SDG 6 Synthesis Report 2018 on Water and Sanitation

More information on UN-Water Reports at: http://www.unwater.org/publications

The United Nations World Water Assessment Programme (WWAP) is hosted and led by UNESCO. WWAP brings together the work of 31 UN-Water Members and 38 Partners to publish the United Nations World Water Development Report (WWDR) series.

The annual World Water Development Reports focus on strategic water issues. UN-Water Members and Partners, all experts in their respective fields, contribute the latest findings on a specific theme.

The 2017 edition of the World Water Development Report focuses on 'Wastewater' and seeks to inform decision-makers, inside and outside the water community, about the importance of managing wastewater as an undervalued and sustainable source of water, energy, nutrients and other recoverable by-products, rather than something to be disposed of or a nuisance to be ignored.

The report's title – *Wastewater: The Untapped Resource* – reflects the critical role that wastewater is poised to play in the context of a circular economy, whereby economic development is balanced with the protection of natural resources and environmental sustainability, and where a cleaner and more sustainable economy has a positive effect on the water quality. Improved wastewater management is not only critical to achieving the Sustainable Development Goal on clean water and sanitation (SDG 6), but also to other goals of the 2030 Agenda for Sustainable Development.

In a world where demands for freshwater are continuously growing, and where limited water resources are increasingly stressed by over-abstraction, pollution and climate change, neglecting the opportunities arising from improved wastewater management is nothing less than unthinkable.

This publication is financed by
the Government of Italy and Regione Umbria

Regione Umbria

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