ELSEVIER

Advances in Chemical Pollution, Environmental Management and Protection

Volume 5, 2020, Pages 189-225

Chapter Five - Drivers, challenges and solutions—Case studies for water reuse

Karl Ulrich Rudolph [a], Birte Boysen [a], Jens Hilbig [a], Faruq Shalizi [b], Keno Stroemer [b], Gabriele Walenzik [a]

CHAPTER FIVE

Drivers, challenges and solutions—Case studies for water reuse

Karl Ulrich Rudolph[a,*], Birte Boysen[a], Jens Hilbig[a], Faruq Shalizi[b], Keno Stroemer[b], and Gabriele Walenzik[a]

[a]IEEM gGmbH—Institute of Environmental Engineering and Management at the Witten/Herdecke University, Witten, Germany
[b]Global Water Franchise Agency GmbH—Office NRW, Witten, Germany
*Corresponding author: e-mail address: karl-ulrich.rudolph@uni-wh-ieem.de

Contents

1. Introduction—The megatrend toward water reuse 190
2. Drivers of water reuse 191
3. Water sector specifics 193
4. The Seven Sins in Local Water Management 193
   4.1 Cost transparency for relevant facilities 194
   4.2 Incentive-driven water service performance 194
   4.3 Demand management of water services 195
   4.4 Political influence at the operational level 195
   4.5 Employment of independent consultants and liable water service providers 195
   4.6 Local water business development 196
   4.7 Impact of structured finance on O&M 196
5. Fields of water reuse application 197
   5.1 Humid vs arid regions 197
   5.2 Commercial vs political water governance 197
   5.3 Industrial vs municipal water management 198
   5.4 Developed vs developing countries 198
6. Case studies of water reuse under different conditions 199
   6.1 Case study I: Financial modeling and water reuse two examples from Windhoek, Namibia 199
   6.2 Case study II: Conversion of wastewater ponds into Lean-Tech ReUse-Water-Plants in Namibia 207
   6.3 Case study III: Water reuse in industrial parks—Opportunities and costs 212
   6.4 Case study IV: Improving water governance through ICT tools and economic incentives in South Africa 217
7. Final conclusion 222
Acknowledgments 222
References 222

Advances in Chemical Pollution, Environmental Management and Protection, Volume 5
ISSN 2468-9289
https://doi.org/10.1016/bs.apmp.2020.07.009

Abstract

The ever-growing demand for water combined with deteriorating water supply infrastructures, misguided investments and overexploited water sources, threatens water security around the world. A promising approach to mitigate this threat is a more widespread introduction of water reuse. However, water reuse is a very complex task and requires well thought out solutions adapted to local conditions. A critical success factor from a management perspective of such complex projects is to avoid the "Seven Sins in Local Water Management" that are a major threat for sustainable operation of water infrastructure and the provision of water related services.

In four case studies, drivers, challenges and solutions for water reuse are presented. A case study from Windhoek, Namibia shows the importance of financial modeling for infrastructure investments including a transparent cost and revenue structure. The second case study describes a lean-tech approach to convert wastewater ponds into reuse water plants for irrigation purposes. Opportunities, costs and drivers for water reuse in Industrial Parks that represent water reuse at a higher technological and operational level are shown in the third case study. The importance of good governance taking into account transparency, accountability and participation is illustrated by a final example from South Africa.

Keywords: Reuse drivers, Governance, Financial modeling, Industrial water reuse, Lean technology, O&M concepts for reuse, Seven Sins in Local Water Management

1. Introduction—The megatrend toward water reuse

More and more people in the world, urbanization, increasing welfare and demand: all this is leading to water pollution and shortage of water supply. On top comes the impact of global climate change. Enfacing this development, the idea from the late 1970s is to shift "from a linear to a circular economy,"[1] meanwhile extended to wastewater management.[2] This idea seems convincing, and it is. However, unlike the problems with global climate change, problems with water shortages are not global but regional and seasonal. Furthermore, the reality is more diverse and more complex than to be characterized as "linear" or "circular," especially in water management. Water recycling is happening in certain industries, but is not always reasonable "Water reuse" or "wastewater utilization" are appropriate key words. The rationale is to work toward *regenerative water management* and to avoid the somehow misleading target of obligatory water recycling "whatever it takes."

Fig. 1 shows that water scarcity can be mitigated by advanced technologies. Even under the worst circumstances, it is always possible to produce

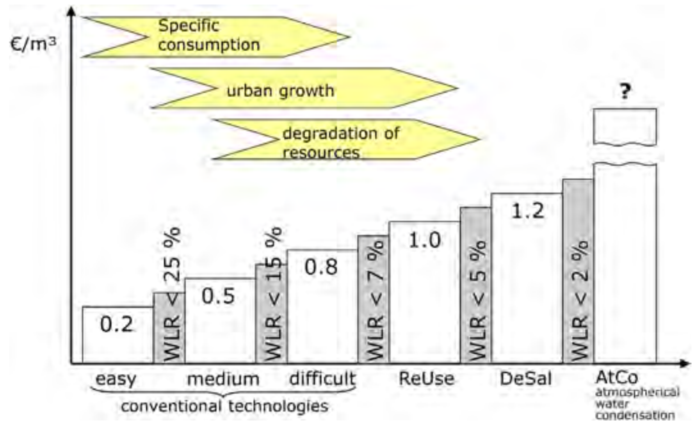

Fig. 1 The cost hierarchy of water production.[3]

enough supply water if there are skills and good management in place. Of course, ambitious technologies and more money is needed to supply increasing numbers of water consumers from natural water resources, which are seldom increasing. Water reuse is not the very top of the ladder, but certainly more challenging than conventional water and sanitation systems.

To save water in times and at locations where water is not scarce may make sense to save resources (chemicals, other consumables, wearables), energy, land, work input and last not least money. The megatrend toward water reuse is justified wherever the megatrend to over-exploit natural water resources for a growing water demand or shrinking natural water resources are real. However—unlike with energy—it is not always an advantage for the environment to save and reuse water. In other words: Water reuse should be motivated and justified case wise in comparison to the use of fresh water resources.

2. Drivers of water reuse

The table below is a list of the most common drivers of water reuse. Scarcity of water is just one among others, even though it can be a dominating reason leaving no other alternative than to go for water reuse Table 1.

In many cases, reuse water is not required all day or year around but needed during the dry season or drought. As far as costs are not for normal consumption but are a safety measure to survive periods of water scarcity it is not correct to benchmark the specific costs for water reuse (€/m^3, \$/m^3…) against the fresh water use. It is more appropriate to calculate the reuse costs

Table 1 Drivers of water reuse.[4]

Driver	Keywords/references
Revenues	• Reclamation water sales (irrigation, non-potable, potable)
	• Energy production (biogas, thermal, mechanical)
	• Valuable substances recovery (metals, polymers, proteins...)
	• Subsidies/taxes (grants, ODA, soft loans, effluent charge, abstraction fee)
Savings	• Supply water (threshold costs/incremental costs)
	• Wastewater treatment (transport, treatment, disposal)
Permits	• Raw water abstraction
	• Wastewater discharge
	• Water consuming industry
	• Water demanding land use
Strategic issues	• Autonomy gain (not depending from water import from external providers)
	• Develop water governance at the local, operational level (revenue inflow for the sale of reuse water will incentivize local wastewater service providers to improve their wastewater services)
	• Improve the "eco image," contribute to SDGs etc.

as general costs to secure water supply and to benchmark safety costs (€/a) against the damage expected in case the supply is interrupted because there is no reuse water available to substitute fresh water.[5]

If water reuse is made obligatory by law without considering the energy, resources and monetary costs it may well happen that the solutions under the law are not environmentally reasonable, not sustainable. Döpkens, Lahnsteiner and Billenkamp[6–8] have reported about their zero liquid discharge projects from India where significant amounts of surplus solid waste, surplus energy consumption, surplus chemicals, wearables needed and additional money required which is not justified by the wastewater discharge avoided and the value of reuse water generated.[6–8] In other cases it is quite obvious that water reuse is more sustainable than for instance a new desalination plant, see Fig. 1. In a nutshell: There is no simple "Yes" or "No" for water reuse in general. It always depends on the case and conditions.

3. Water sector specifics

With the exception of the provision of goods and services from industry-to-industry, there are significant specifics characterizing the water sector which everyone thinking about water reuse should be aware of.[9]

A Wastewater service utility

- primarily serves government standards (e.g. wastewater treatment for water protection),
- rarely has direct customer relations (e.g. water purification by order of a local authority),
- mainly works for public customers (e.g. municipalities, municipal associations, public utilities),
- is usually subject to public procurement (and rules of the financing donor banks, municipal loan, etc.),
- is mostly a service provider for politically priced services (water, waste, recycling, renewable energies).

This may change somehow when purified wastewater is sold as "secondary water" for water reuse, but to make it work, the most important of the traditional weaknesses in the water sector need to be cured.

4. The Seven Sins in Local Water Management

As outlined above, water reuse is more demanding than conventional water supply regarding required technologies, management of utilities and infrastructure, and institutional frameworks. Furthermore, water supply attracts more political and managerial attention then wastewater management, because protests of the people come quickly when water supply is cut whereas malfunctioning wastewater treatment facilities may happen without any reactions from the public or late reactions after the damage to the receiving water bodies and the environment has happened. As soon as wastewater is utilized respectively water reuse is introduced, this situation may change because all of a sudden wastewater turns out to be part of the water supply value chain. For water reuse, it is even more important than for fresh water use to acknowledge the most important success factors, which have often caused failure in local water management respectively, lead to success. If addressed and well implemented, the most important seven issues can be considered as seven success factors. If not—as, unfortunately, found in too many cases worldwide, especially in developing and emerging countries—the seven issues must be named what they are: seven sins against local water management.

Below is explained, WHY the sin under discussion needs to be addressed, and HOW it could be dealt with.

4.1 Cost transparency for relevant facilities

WHY? Without knowledge about real costs, no city council or utility leader can take rational decisions, be it about technical, managerial options, tariff strategies or water business planning with or without water reuse. Currently, too many decisions are made in an information vacuum.

HOW? Financial modeling should be established, as far as possible, adapted to the structure of the utilities' bookkeeping with common tables and lists. It may help to visualize CAPEX and OPEX, show major cost components, tariff revenues, cash flow, accumulated tariff balance, debt ratio etc.—not to forget the ratio of real vs sustainable O&M (operations & maintenance) the sustainability benchmark can be based on rough assumptions of asset replacement value, as far as asset register data are not existing. NOTE: O&M expenses below the sustainability benchmark may cause high surplus costs in the future. In the first case study two examples of successful financial modeling in Windhoek are given.

4.2 Incentive-driven water service performance

WHY? Without incentivizing the people responsible for water management success on the local, technical, operational level, it is unlikely that water facilities are well functioning. O&M is a major bottleneck of success in water service performance and the first expenditure, which treasurers like to cut in times of financial difficulties unless stopped by protests of O&M stakeholders.

HOW? There is a lot of literature and shiny brochures but few examples from municipal water utilities in developing countries. Donor banks have issued guidelines on how to apply reasonable key performance indicators (KPI). For public-private partnership (PPP) contracts with private service operators performance-based incentives are quite common and can be a good role model to consider. The distribution of penalties and bonuses (monetary and others) among the different staff levels (from water utility CEO to facility operators) is important.

4.3 Demand management of water services

WHY? Sufficient power to control water consumers' behavior is necessary to make sure that water is saved and not wasted. Low, subsidized tariffs, flat rate tariffs, poor collection rates, legal barriers to cut or limit water supply can ruin all efforts for reasonable water demand management and finally the quality of water services.

HOW? Water demand management can be targeted as one element of water efficiency, in combination with water loss reduction programs addressing physical losses (leakages) as well as administrative losses (water theft, unbilled or unpaid water consumption). Digitized water metering, leakage and pressure control is much easier than it was in the past. Reuse water may well be subsidized except during drought periods.

4.4 Political influence at the operational level

WHY? Public entities and municipal water utilities are under political governance. This is justified for political decision-making, but not for the operational execution of what has been decided. Execution fails without executives empowered to act according to managerial, technical, entrepreneurial needs.

HOW? Ring-fenced utilities (not necessarily established as autonomous legal entities, but committed to act as a company, with the council as shareholders, the utility leader as CEO) can be a good way to make sure that the different political and executive roles and players are clearly defined and strictly separated.

4.5 Employment of independent consultants and liable water service providers

WHY? Consultants, such as scientific or professional engineering, financial advisers are necessary and can be of great help for water utilities. However, warranties for constructions and equipment, contractual compliance with water quality standards, binding unit or lump sum prices can be delivered by liable providers of goods and services, not by consultants working on hourly or daily fee basis. Vice versa, independent advice without conflict of interest to select between competing technologies or services may come from consultants, not from entrepreneurs.

HOW? Understand the basic rules of a soccer match: A consultant is like a referee or entrusted coach but not a provider of goods (like water technologies) or services (like O&M, water facility management). In most developing countries and emerging markets there are too many consultants involved. Use conventional consultancy, municipal twinning, water operator partnerships and others (be it non-for-profit or commercial) to prepare procurement and supervise liable providers of goods and services. However, do not substitute liable technology and service providers with consultants.

4.6 Local water business development

WHY? The slogan "one job per drop" has spread around the globe. Water and environmental services can support the development of the local economy significantly. This will support the political acceptance and willingness to pay for good water and sanitation services supporting the SDG targets.

HOW? The international and national procurement regulations, as well as the regulations of donor banks, are seldom made up in a way that local companies are encouraged to bid. However, there is often room to reduce the bureaucratic burden and reduce the volume and complexity of tender docs and procedures. Design work packages in a way that certain lots become attractive for local entrepreneurs, in terms of risk share (allocating technical and financial risks to the contractor only if these risks are in the contractors' sphere of influence) and in terms of obligations (request skills which are available in the local provider market). For ambitious works, make sure that the international provider employs local companies in a way that the local market can develop further.

4.7 Impact of structured finance on O&M

WHY? For good reason, donor banks demand sovereign state guarantees, and, in addition, are risk-protected under the umbrella of their governmental shareholder(s). Commercial banks are bearing financial risks and suffer if their borrower does not generate revenues for debt repayment as planned. Therefore, commercial banks are strongly committed to make things work, from design to construction to production, water service. The zero-risk investment finance is one reason for sunk investments in the water sector of development and transition countries, with insufficient O&M being a major bottleneck of success.

HOW? Blended finance, or how the author would prefer to say, hybrid finance with a minimum component of private risk finance contributed by commercial (private) banks would be a reasonable solution provided the risks under the risk-sphere of project development and execution are not socialized through hidden risk guarantees to the disadvantage of taxpayers or water consumers. Whenever this option is available, lenders should prefer loans from financing institutions with a commercial component, if ever possible reflected in the Financial Agreement.

5. Fields of water reuse application

Reflecting the water sector specifics as described above different fields of application for water reuse can be classified. It is obvious that the restrictions, the drivers, the working conditions for water reuse are quite diverse in the different fields of water reuse application. The following fields seem to be of logical and practical importance:

5.1 Humid vs arid regions

No doubt, in humid regions there is more freshwater, and the value gain through water reuse is not as high as in arid regions with water scarcity. Windhoek, the *cradle of direct potable water reuse*[10,11] had to go for direct portable reuse in 1968 because there was just not enough fresh water in this very arid region with only 360 mm/a of precipitation as described in the first case study. Singapore is producing potable reuse water under the brand "New Water" since 2003 to become independent from water import. With 2340 mm/a it is very humid there, but not enough to supply this densely populated area with fresh water from local resources (Singapore has 7804 persons/km^2, Germany 240 persons/km^2 and Namibia only 3 persons/km^2). As mentioned above, urbanization and increasing number of megacities cannot be water supplied without water reuse even in humid areas. Another example is New Zealand, where water reuse for agricultural water is enforced in sensitive areas, not because of the lack of fresh water but because of the restriction to percolate nutrient loaded run-off into the groundwater. In countries like Germany with high wastewater fees, water reuse can make sense just to avoid the fees for wastewater discharge into the public sewerage respectively wastewater levies for discharge into receiving water bodies.

5.2 Commercial vs political water governance

Commercially governed water utilities will go for water reuse (1) if this is obligatory under the law or to acquire public permissions, (2) if internal sustainability standards are part of internal financial risk assessment or (3) if water reuse is a part of their balanced scorecard, business strategy.

For politically governed like public water utilities the City Council or other politically bodies are responsible as shareholders. Similar like in industry, the financial considerations play a role, of course, and sustainability aspects beyond money are part in their decision-making. The main difference is that commercial utilities cannot survive without commercial power (=money), whereas political bodies cannot survive without political power (=votes). Therefore, because water reuse is a megatrend, public water utilities are more likely to take financial risks to gain best-positive image of water reuse, whereas commercial water utilities are more likely to take risks in political relations to gain best-possible financial benefit. The importance of functioning governance is shown in case study IV.

5.3 Industrial vs municipal water management

As a matter of fact, water reuse is more common and further developed in industry, than in public water systems. This has developed due to technical and economic reasons. One reason is that the recovery of energy and valuables is easier near-to-source in factories than in municipal wastewater systems handling mixed wastewaters from various sources and qualities. Another reason is that environmental standards are more expensive to fulfill for many industries than for municipalities because mixed respectively domestic wastewater is less concentrated, contains less contaminants, toxic agents than certain (not all) industrial wastewaters. Furthermore, the political decision makers often choose industry first to set and enforce stringent standards, and are more cautious to set or enforce standards for municipalities with many customers and voters who dislike paying higher wastewater fees. In the third case study reuse opportunities in an Industrial Park are described.

5.4 Developed vs developing countries

The connection rates and standards of water systems in developing countries are lower than in industrialized, developed and more wealthy countries. With water reuse, more managerial capabilities and more money to design, build, operate water infrastructure facilities are needed. However, since no life is possible without water, and no civilization or human settlement without water supply, water reuse had to be realized in the past for some and will have to be realized in more and more cases including developing countries. Since many years, the largest systems of wastewater utilization practice unofficial water reuse without proper wastewater purification and with considerable risks.[12] Customized reuse concepts for developed countries are shown in case study III and for developing countries in case study II.

6. Case studies of water reuse under different conditions

The first case study explains the financial modeling of an investment to convert a conventional wastewater treatment plant to an advanced wastewater treatment plant for raw water production, ready to be further processed in a potable water production plant. The second case study deals with a low-cost solution to upgrade existing wastewater ponds to produce water for irrigation. The third example includes high-tech based concepts for water reuse in industrial zones. Finally, a fourth case study outlines the importance of good water governance including water quality monitoring and ICT governance for successful water resources management.

6.1 Case study I: Financial modeling and water reuse two examples from Windhoek, Namibia

6.1.1 Introduction—Initial situation and objectives

Over the last decades, numerous efforts and investments in the billions of euros have been made to improve the water supply situation and satisfy the ever-increasing demand in developing countries and emerging markets. However, the results have been underwhelming and the majority of developing countries and emerging markets are currently facing a water crisis of historic proportions.[13,14] This presents a serious threat to their socio-economic development.

A key challenge faced by water utilities around the world is that simply increasing water supply, as was successfully done in the past,[15] has often reached its technological and/or economic limits. Most available water resources are already overexploited and the exploration of new freshwater sources is either too expensive or limited due to the reduced availability of untapped water resources. Therefore, water loss reduction measures and demand-side approaches which are more difficult to implement are required to improve resource allocation and secure water supply.[16–18] In very arid climates, however, water loss reduction measures and demand-side approaches are sometimes not enough to ensure sufficient water supply.

One additional major but often disregarded hurdle in improving water supply are the water utilities' unsustainable business models which lead to a mismanagement of water resources and finances.[19–22] In fact, the existing business models with inadequate tariffs and a lack of financial modeling in emerging markets represent one of the main reasons as to why so many of the past investments have failed to secure long term improvements in the water supply.[22–25] Due to a widespread lack of financial modeling in developing countries and emerging markets, cities often have hardly any overview of their financial situation concerning water supply and wastewater treatment and tariffs are often set too low. As a consequence, there are insufficient funds for O&M which causes leakages and a drastically reduced service life of the infrastructure.[13,26] Moreover, investments to improve the situation can often be tailored neither to address the most pressing weaknesses (from an economic point of view) nor be realistically assessed in terms of their benefits as there are no reliable key figures that could serve as a baseline.

Both of these challenges can be addressed and to some extent counteracted with the help of financial modeling and water reuse. A sustainable business model, including the financial modeling of the water supply and wastewater treatment departments and infrastructure, would increase transparency and be able to address, inter alia, the issue of misguided and/or unsustainable investments, increase resource allocation efficiency and reduce water wastage by appropriately pricing water and wastewater services.[23,27] For arid regions with few water resources, water reuse can be a viable and often economically sensible option to increase water supply and security.

The City of Windhoek (CoW), which is located in a very arid region, was faced with these two challenges and managed to address them. In Windhoek, the average annual precipitation is 360 mm, and the evaporation is between 2600 and 3700 mm. During the annual drought periods, there is extreme water scarcity; and since it was not technically or economically feasible to increase water supply by traditional means (e.g. by building more dams or new bore-wells), the City decided to make significant investments to establish direct water reuse. After commissioning of the Goreangab plant in 1969, Windhoek, often referred to as the *cradle of direct potable water reuse*, became the first city in the world to process drinking water from wastewater–long before Singapore, Australia, California, South Africa and other cities and regions followed suit.

This subchapter briefly discusses two key investments by the CoW to secure and expand direct water reuse and thereby water security. First, the construction of the Ujams plant to treat all industrial wastewater in the city. The wastewater is treated at Ujams to a level sufficient for potential non-potable reuse. Second, the upgrade of the wastewater treatment plant Gammams to an advanced wastewater treatment plant for raw water production for a new direct potable reuse plant. A strong focus is hereby placed on the importance of financial modeling.

6.1.1.1 The wastewater plant UJAMS

To achieve a better quality effluent available for reclamation, the wastewater infrastructure was adapted to enable the separation of the industrial wastewater from the domestic wastewater and to direct it toward the Ujams Wastewater Treatment Plant (UWTP). Due to the separation of the industrial wastewater, the remaining wastewater is less polluted and easier to treat for direct potable reuse. As of now, the UWTP has been in operation for more than 35 years and is still solely responsible for the treatment of all effluent generated in the Northern Industrial Area of Windhoek. The CoW assigned the author (as part of an international consulting consortium) to advise on the final design of the PSP (private sector participation) concept (including a financial feasibility analysis of different technological solutions), on the design of the BOT (build, operate transfer) contract and to manage the tender process. To assess the feasibility of the project and the likely impact on the wastewater tariff the authors used financial modeling.

To minimize technological and operational risks and gain access to external financial sources, CoW opted for a BOT contract with private financing. Since commissioning, the plant is operated successfully and is considered one of the very few high-tech plants in Africa under sustainable public governance and professional operations.[4]

6.1.1.2 The wastewater plant Gammams

One of the CoW's most urgent water reuse investment-project currently under preparation is the rehabilitation and upgrade of the Gammams wastewater plant. The plant is supposed to produce raw water for further processing in the existing New Goreangab potable-water production plant and a newly planned direct potable reuse plant. However, Gammams is currently operated over design capacity and often unable to meet the presently required effluent standards. The plant consequently needs to be rehabilitated and upgraded.

Initially, the project was planned to be realized under an EPC (engineering, procurement, construction) through the municipality. Yet, being aware of the technological and financial risks and eager to create a holistic competition on life-cycle-cost-basis (incl. Investment plus operational costs), the City decided to go for a DBO (design, build, operate) model. As with the investment for Ujams, the investment is justified by the financial benefits and increased water security.

For both case studies extensive financial modeling was required.

6.1.2 Methodology and benefits of financial modeling

Long-term, capital-intensive investment projects in the water and wastewater sector require extensive cost calculations in advance to assess the overall feasibility and economic sustainability of any project. Furthermore, several parameters are controllable and need to be timed and estimated efficiently, e.g. loans, (replacement) investments, cost and revenue structures. The Windhoek Financial Model is a MS Excel-based spreadsheet model that incorporates the most common calculations occurring in water supply and wastewater treatment projects (e.g. the impacts of the investments on the tariffs, forecasts of the future revenues and expenses, scenario analysis for different tariff and tariff collection developments).

It enables the user to evaluate investments requiring only a relatively small number of basic inputs while considering the overall effect on the general financial situation as it incorporates all water and wastewater-related facilities and/or cost centers. The authors have developed this model specifically for the Gammams Wastewater Treatment Plant (WWTP) Upgrade Project—a predecessor with a more limited scope was used for the Ujams investment Fig. 2.

The Windhoek financial model has been developed with MS Excel 2016. It uses MS Excel's innate VBA (Visual Basic for Applications) programming language for certain macro-based events. The model is defined by a logical flow of information, always flowing toward subsequent sheets and never backward. Due to the complexity of certain calculations, that principle cannot be maintained within single sheets themselves, but circular references are non-existent. Optimal results will be achieved if every sheet is filled in successively. Alterations of values in earlier sheets are, of course possible—due to the flow of information throughout the model, these alterations will then correspondingly change results in all subsequent sheets. Most sheets within the model have the same structure. A timeline at the top of the screen depicts the timeline in years, while the left-hand side represents the respective parameters. MS Excel's freeze window function ensures that both project years and parameters remain visible, irrespective of the user's scrolling through the sheet.

This universal design allows using name ranges for calculations. Thereby, when selecting a certain cell, relevant components of each calculation formula are intuitively comprehensible due to the use of name ranges instead of simple alpha-numeric cell references. Additionally, every sheet has a header that provides information about its contents. Finally, the entire workbook is protected. The only cells that can be altered by the user are input cells.

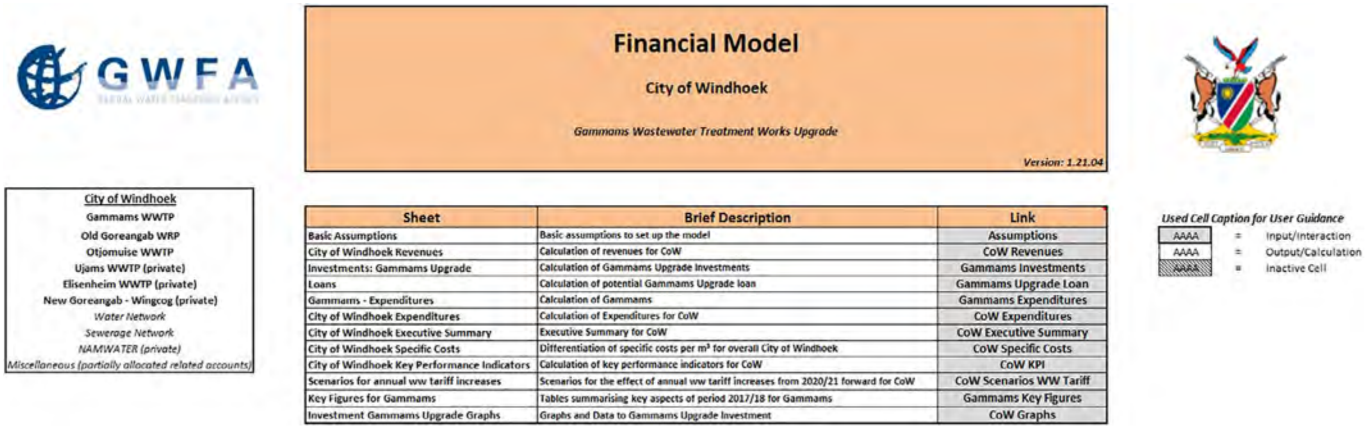

Fig. 2 Screenshot of the financial model's navigational sheet.

This ensures the overall integrity of the model and prevents almost untraceable calculation errors due to accidental alteration of cell formulas.

Since the financial model is based on standard software and includes a detailed manual, most utilities should be able to replicate it and adapt it to their needs. This is of particular importance for utilities in smaller and medium-sized cities in emerging markets as they often lack the funds and/or qualified staff to use expensive and more complicated software.

A financial modeling of the utility's water and wastewater departments and upcoming investments is of great importance as it provides the utility with the basis to sustainably improve water supply. A comprehensive financial model offers several benefits to the utility[22]:

(i) The model provides transparency and allows the utility to fully understand their cost and revenue structure. It also enables the utility to identify their weak points, such as low collection rates:

(ii) It also serves as a tool to verify if the available data it depends upon (i.e., audited accounts and loan sheets) is reliable and consistent as discrepancies in data can easily be identified in the financial overviews of the model;

(iii) It enables the utility to calculate and forecast numerous scenarios (e.g., a change in tariff or collection rates, a change in the number of collected households, a change in water demand, the viability of investments and their consequences, and the automatic calculation of tariff levels and collection rates necessary to recover the costs);

(iv) It creates a basis that allows the municipality or utility to apply for external funding and grants more successfully since transparency concerning the financial situation is in most cases a prerequisite for commercial and donor banks as well as government institutions to provide funding;

(v) In a similar vein, it is essential for ex-post evaluations of any investments into the system, which have recently become a more common demand for donor-financed and public investments[28];

(vi) A transparent overview of the significant costs caused by providing this service could improve public and political acceptance for the water tariffs.

The following screenshot (Fig. 3) illustrates the effect of the investment on the tariff as calculated by the financial model. It shows how the tariff needs to be increased to cover the costs of wastewater treatment in Windhoek and the investments for the Gammams upgrade. The red line shows the required percentage annual tariff increase per year to recover all costs at the end of

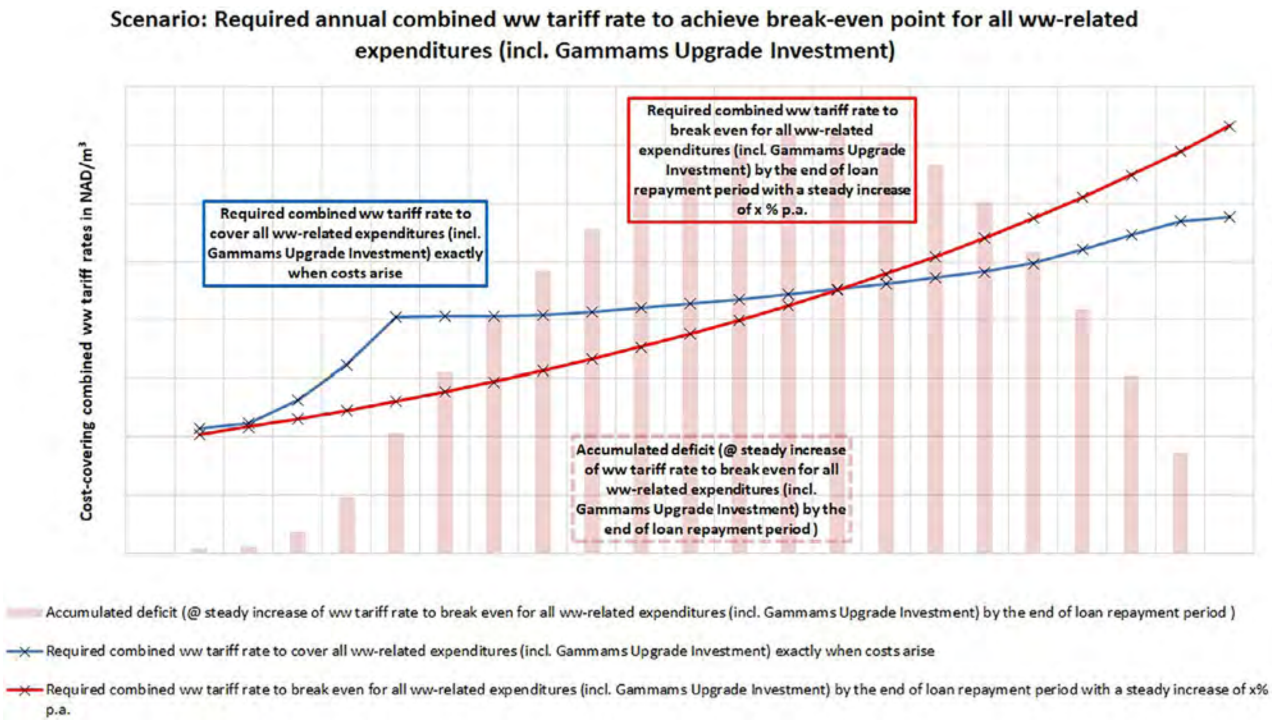

Fig. 3 Scenario analysis—cost recovery for gammams investment.

the loan period; the blue line shows the required tariff increases at each year to recover all costs in the year they arise. Due to a confidentiality agreement, the exact figures of the calculations cannot be shown.

6.1.3 Results and conclusion

From an economic point of view, the financial modeling showed that the investments in Ujams were beneficial for the City since the surplus costs for a new industrial wastewater treatment plant UJAMS with effluent quality for non-potable water reuse were justified by the surplus benefits compared to purification according to the stringent standards set under the law. The same is true for the planned investment in Gammams where the investment secures the production of raw water for the direct potable reuse plants. Moreover, the combined costs of the wastewater treatment at Gammams after the upgrade and the costs of New Goreangab per cubic meter are lower than the current price for piped bulk water from the Central Area of Namibia. The financial modeling of the CoW's water and wastewater infrastructure significantly increased financial transparency and revealed among other things that the city suffers from very low tariff collection rates, which prevent the utility to recover the costs of water supply and wastewater treatment. The low collection rates can partially be explained by the City's socially motivated approach to writing off debt for the elderly and the very poor. However, at some point, the collection rates will have to increase to avoid disproportionally high increases in the tariff rates.

From a technical side, the importance of direct water reuse can be seen in Fig. 4.

In Windhoek, during normal supply periods, 75% of raw water is abstracted from surface water. However, during drought periods as in 2017, less than 3% of the water demand could be supplied from surface water. Some of this decrease in supply could be offset by an increase in water

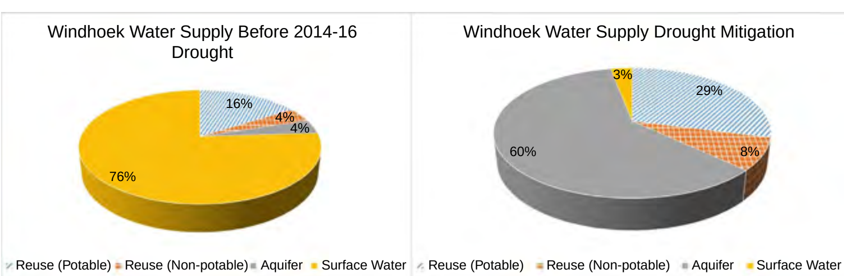

Fig. 4 Importance of DPR in Windhoek water supply according to Ref. 10.

reuse which already supplies 16% of the water in a normal season and was increased to 29% in the drought period. However, despite the fact that all water production facilities were exploited to its maximum (additional surface water import and groundwater extracted from the aquifer as much as all pumps could deliver for a limited time period) during the drought, and although the water reuse was increased to full capacity of the treatment plant, it was not possible to serve all supply needs. Stringent control of water consumers had to be executed as emergency measures of water demand management (WDM). On average, the daily water consumption had to be cut by 25%. The results of financial modeling have revealed, at which rate of tariff increase such significant WDM measures can be avoided. For the future, it is predicted that the water deficit will continue to grow due to increasing water demand and decreasing availability of raw water.[29] More investments are consequently necessary.

Water utilities should, however, not regard standalone infrastructure investments as a panacea to improve water supply but should always focus on establishing business models for water utilities that allow them to operate the network sustainably and price water according to its costs. The authors of this paper propose that the developed financial model or similar models should be included as an integral part of business models for water utilities in emerging markets before or simultaneously to any new infrastructure investments. The authors believe that it should be possible to transfer the financial model to other cities since the basic underlying economic principles for water supply are nearly universal. If it becomes apparent that even with demand management and low leakage rates, water supply cannot be secured, water reuse should be considered as a viable option and the necessary investments and benefits should be compared to other solutions such as desalination plants with the help of financial modeling.

6.2 Case study II: Conversion of wastewater ponds into Lean-Tech ReUse-Water-Plants in Namibia

6.2.1 Initial situation and problem statement

The descending of stressed water resources and increasing water demand are among the most serious concerns in Africa.[30] The urbanization in many African cities leads to overloading of the wastewater treatment plants, which are often implemented as unaerated pond systems.[31] Overloaded and overflowing ponds cause health risks for humans and animals.[32] Furthermore, increasing droughts and more variable patterns of rainfall are predicted for Namibia which will increase vulnerability of farmers.[33]

In Outapi, a town with 7000 inhabitants (and an annual estimated population growth of 9.3%; 2011) in northern Namibia close to the Angolan border, the bottleneck of wastewater treatment is the evaporation pond, which during flooding events overflows. By treating the wastewater to a level suitable for irrigation, several problems are solved at once. The scarce resource of water is used efficiently and therefore other water sources are relieved and farmers are able to operate independent from rainfall. Additionally by using the water currently led into the evaporation pond, said pond is unburdened and overflows will be prevented.

6.2.2 Project objective

The objective of EPoNa is to develop and demonstrate how existing wastewater ponds can be rehabilitated and extended in a combination of pre-treatment, post-treatment and technical pond improvements, up to a standard that allows reuse of the wastewater for irrigation of fodder plants. The focus in this case study is on the Bio-Percolation-Filter as a low-cost and lean-tech solution[30] for post-treatment in combination with local business development.

6.2.3 Methodology

To implement the water reuse approach, a pre-treated line (Line A) of an existing two-line evaporation pond system in Outapi was equipped with a dolomite rock filter as a secondary treatment stage. Its treatment efficiency is compared with the second similar constructed line (Line B) without any pre- or post-treatment improvement as shown in Fig. 5. For pre-treatment a micro screen can be chosen, its high efficiency is shown by its minimum space requirements and simultaneously high removal efficiency of organic and mineral particles.

The overall design philosophy of the Bio-Percolation-Filter is to keep things as simple as possible. In general, suitable stone material is available locally and can be integrated into existing ponds without high tech machinery and concrete constructions.

The filter is created with two layers, the inner rocks are smaller to create a bigger surface and pore volume for particles to settle and sessile bacteria to grow. The outer rocks are bigger for hydraulic unification, breaking water surface tension and improving natural aeration of the pond. To drain the water from the rock filter, a perforated pipe is buried horizontally inside the filter bed and connected with a collection chamber.[34–36]

The aim of the Bio-Percolation-Filter is to reduce the concentration of algae and germs and hold back a certain amount of solid particles.

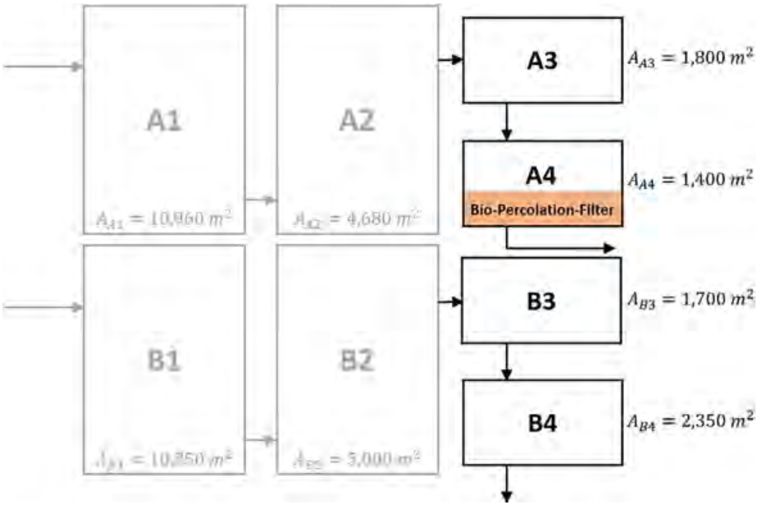

Fig. 5 Pond line system Outapi.

Fig. 6 Rock filter after commissioning and rock with biofilm after operational start-up.

These percolate horizontally under gravity flow as well as become attached to the rocks where biologically active surfaces induce decomposition (see Fig. 6). The algae are broken down, releasing nutrients consumed by the bacteria, which grow on the submerged rock surface. The treatment operation of the rock filter is completely based on natural process, and depends on the loading rate, temperature, size, and shape of the rocks. In addition, the filter efficiency for the degradation of organic substances depends largely on the biological turf on the surfaces of the filter material, which, due to the non-addition of biofilm-promoting bacteria, must grow over a period of months.

6.2.4 Results and conclusions

The measurement results to date show a clear and steadily increasing COD reduction performance (see Fig. 7), recognizable by the improvement in the

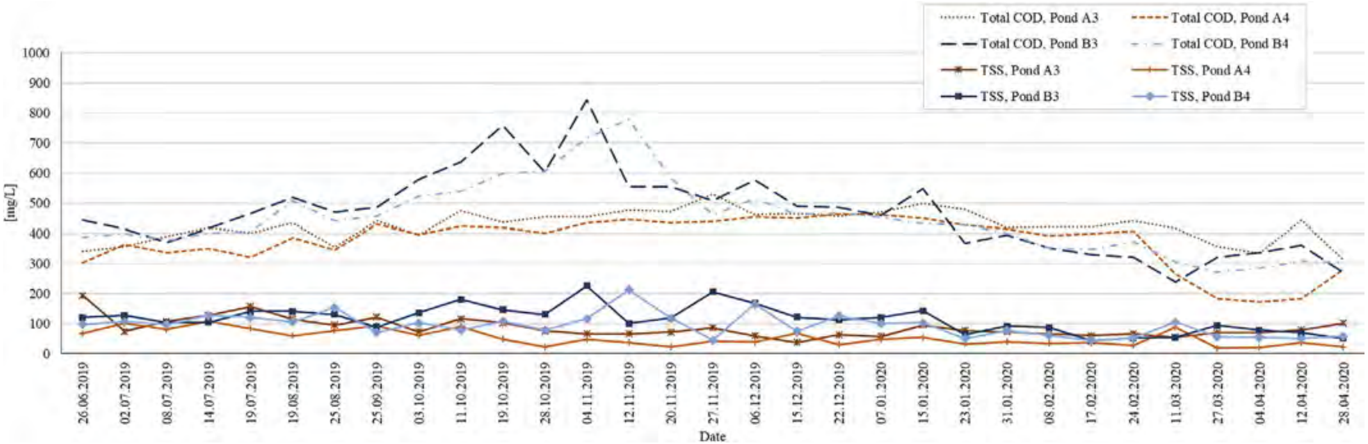

Fig. 7 Rock filter effect on TCOD and TSS Load.

reduction rate, within 10 months, from 7.5% to 33%, which is complementary to biofilm development. A significant reduction gradient was observed for TSS during this period, so that the reduction rate could be increased from 25% to 45% on average.

Overall, the results so far show promising purification tendencies and provide a good basis for further verification of the filter performance.

The positive effect of the rock filter design philosophy becomes evident when looking at the cost of the project. In a first economic evaluation the Bio-Percolation-Filter investment and operational expenditures only make up about 10% of the total expenditures of the upgraded pond system (see Fig. 4). Using mostly locally available materials and local workforce in combination with the general low-tech solution is a comparatively inexpensive solution, hence an ideal approach for the extension and upgrading of existing ponds (Fig. 8).

Combining these first economic results with the reduction in load, the high cost efficiency becomes apparent. The TCOD elimination of pre-treatment makes ca. 20% of the total TCOD elimination including the post-treatment. Even if the reduction in COD is only partially attributable to the Bio-Percolation-Filter, it is still an efficient solution to generate water for limited reuse purposes.

Overall, it can be stated that the microorganisms on the biofilm purify the wastewater that enters the percolation filter and raise its quality to a level that is suitable for restricted low-pressure drip irrigation. Hence, the defined objective can be reached in an affordable way with locally available resources, which enhances local economy and the living conditions of

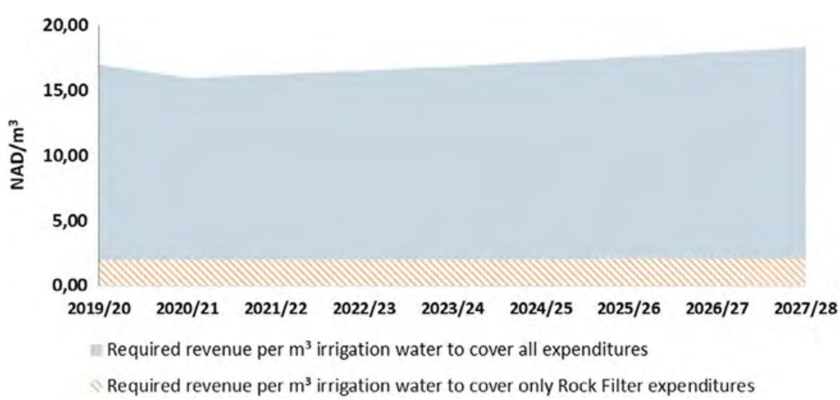

Fig. 8 Required revenue per m^3 of irrigation water produced in pond line A to cover all upgrade expenditures vs expenditures only for bio-percolation-filter ("Rock Filter").

humans as well as flora and fauna improve. If operated and maintained professionally, this option can be replicated in many other wastewater pond systems throughout Africa and elsewhere.

6.3 Case study III: Water reuse in industrial parks—Opportunities and costs

6.3.1 Initial situation and problem statement

Water is an essential production factor for companies[37] therefore the availability of water can be crucial and an important decision factor in location selection. More often companies settle in industrial parks which leads to a high water demand in a certain region and can cause over-exploitation of local water resources.[38] Low levels of surface water can cause conflicts of use for example between local industry, agriculture or shipping.[39,40] To secure water supply for industry parks and help overcome possible future water shortages, industrial wastewater can be reused. The joint project "Water Reuse in Industrial parks" (WaReIp) the wastewater generated in industrial parks is analyzed, and its demand-oriented treatment and reuse for various purposes is assessed.

6.3.2 Objective

To enable and increase water reuse within industrial parks, all relevant solutions need to be presented and compared to alternatives. The objective is the development of a modular and easily adaptable planning and assessment tool including economic aspects for water management concepts in Industrial Parks (IPs) focused on water reuse and resource protection.

6.3.3 Approach and methodology

In general, there are different opportunities for wastewater treatment and non-potable (waste-) water reuse in industrial parks as shown in Fig. 9.

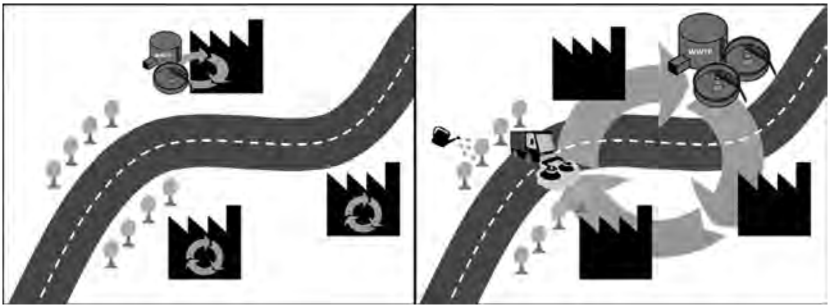

Fig. 9 Opportunities of water reuse in industrial parks.

Treatment can be decentral or central and purposes of reuse water can for example be for industrial production or IP infrastructure. Water reuse can be internal within one company producing, purifying and reusing wastewater may be for its cooling systems, to clean production facilities etc. A paper factory (established in one of the German IPs supporting the WaReIp project in the research advisory board) has closed its water cycle internally as far as possible and reuses as much as 80% of the required water in the newly built paper production plant. Besides water reuse, the company generates biogas and recuperates thermal energy as well as valuable materials and becomes less dependent on external sources.

Other IPs practice decentral pre-treatment to further treat in a central wastewater treatment plant, the common option in Vietnam, where certain quality standards are required before discharge of industrial wastewaters into the IP sewerage system.[41] In other cases, central wastewater treatment plants (CWWTP) serve all companies within an industrial park and supply reuse water for infrastructure and production purposes within the IP compound. Here lies the main focus of WaReIp, to research technology based solutions for CWWTP combined with a Water Reuse Production Plant (WRP) and year round water reuse for IP infrastructural purposes. Infrastructural purposes are chosen due to companies' inexperience with (or reluctant attitude toward) fluctuating or lower water qualities for production processes. A further option are semi central WWTPs where the wastewater of multiple companies is (pre-)treated.

To be able to evaluate and benchmark water reuse in an IP the Industrial Park Reuse Factor (IPRF) is introduced, describing the relation between the wastewater inflow into the CWWTP and the reuse flows. With the creation of a WaReIp Model Industrial Park (MIP) the IPRF as well as possible cost of a reuse in an IP can be calculated exemplary.[42]

The MIP is based on German, Chinese and Vietnamese experiences and data and consists of production plants from several industries including chemical, paper, food and beverage production. Furthermore, the canteen as well as sanitary wastewater is considered as source of non-potable reuse water. Reuse purposes include infrastructure usages like irrigation of greenspace, and street cleaning as well as toilet flushing and possibly cooling water. The cooling water is considered to be recirculating as it is common in water stressed regions and therefore considered 2% of the cooling water demand. The calculation of the water demand for toilet flushing is calculated with the number of employees and 40 L per employee per day. Street cleaning and irrigations water demand is calculated via the respected areas with 2.5 L and 2.0 L per day per square meter.[42]

To demonstrate different opportunities the reuse is divided into three options:

1. Option (O1), the WRP is installed to treat approximately 5% of the wastewater from the MIP to cover the demand of street cleaning and irrigation water (i.e. 5150 m^3/day).
2. Option (O2), the reuse factor is increases to 7% in order to cover the demand of street cleaning and irrigation water, and toilet flushing water (i.e. 6566 m^3/day).
3. Option (O3), the reuse factor increases to 14% in order to cover all the water demands for infrastructural purposes including cooling water (i.e. 13,479 m^3/day).

The non-reuse option (NRO) refers to the situation in which the total wastewater flow from the WWTP is emitted to a river and the water input is from surface water or ground water.

The planning and assessment tool for water management concepts is based on a library of process modules for water treatment (developed in the project), which contains technical process information as well as the calculated economic and environmental data. This library can be used for the planning to simulate different combinations of treatment technologies and wastewater volumes.

Further assumptions of the MIP include an 8% loss of reuse water in the supply network. Considering losses and backflows, the WRP capacity is modeled for 125% of nominal production. Energy and chemical demands were calculated for the mean flow rate. Furthermore, the sewage sludge was not included in the calculations of the MIP, because specific local conditions are very different.

Economic and financial aspects take on a major role in the assessment and planning of integrated wastewater concepts for industrial zones[43] and are therefore a part of the WaReIp planning and assessment tool. The profitability of reuse depends on the existence and compliance of wastewater discharge standards. When the required discharge quality is high already, the delta to required reuse quality is low and only the cost of the reuse facility can be considered and compared to alternative water resources. For the MIP this is assumed to be the case and the examined WRP consists of sand-filtration, UV disinfection and chlorination. Therefore the costs of the process steps can be compared with the cost of the NRO.

Costs depend on various circumstances, variables and can therefore vary greatly in different cases. For an initial assessment the tool developed within WaReIp can be used. To be able to compare different reuse options with changing volumes cost functions are used for CAPEX calculations. OPEX are calculated with operational data from the WaReIp process modules and price inquires for the supplies. For a first assessment, the MIP is calculated with municipal German cost data. Computed are yearly costs and costs per cubic meter. A calculation model is built in a modular way to allow for variations and scenarios with different technologies and process chains. The modules integrated in the WaReIp calculation model include sand-filtration, UV disinfection, chlorination and pipeline network. Each of these modules can be modeled independently so that both the individual effect of a module and its weight in combination with other modules can be evaluated to form a complete water reuse concept.

6.3.4 Results and conclusion

Every company located within the IP needs to decide for itself how much internal reuse and which quality and how much reuse water can be used in production. The IP can additionally focus on centralized reuse for infrastructure purposes.

In the WaReIp Model Industrial Park with German cost data the calculated cost per cubic meter are shown in Fig. 10.

Comparing the MIP interim results, O1 has the lowest costs per m^3 of produced reuse water, mainly because it does not integrate costs for the pipeline network, because tankers are used to distribute the water. If the pipeline network costs for O2 and O3 are neglected, there is a trend of slightly decreasing costs per cubic meter with increasing size of the water reuse volumes is identifiable. Economy-of-scale is an important factor when considering different reuse options; it might lead to a lower cost per m^3 if an additional application for a higher water reuse quantity is calculated.

The conservatively calculated WaReIp results are higher than those stated by Bischoff where UV costs are said to be in the range of 0.02–0.03 €/m^3.[44] Costs for sand-filtration are reported to range between 0.03 and 0.15 €/m^3 depending on site-specific conditions.[45] Chlorination with gas can be as low as 0.03 €/m^3[46] and chlorine dioxide as an alternative is reported to range between 0.05 and 0.13 €/m^3.[44]

Alternative water supplies in the no-reuse option are the usage of tap water or the abstraction of river water for cooling. To abstract water from a river in Germany a permit is required (Wasserhaushaltsgesetz WHG § 8; Federal Water Act article 8), for which a fee is charged (this fee is a cost component, but not necessarily the value of the water abstracted). Given the assumed volumes in the MIP such a fee would be below one cent per m^3

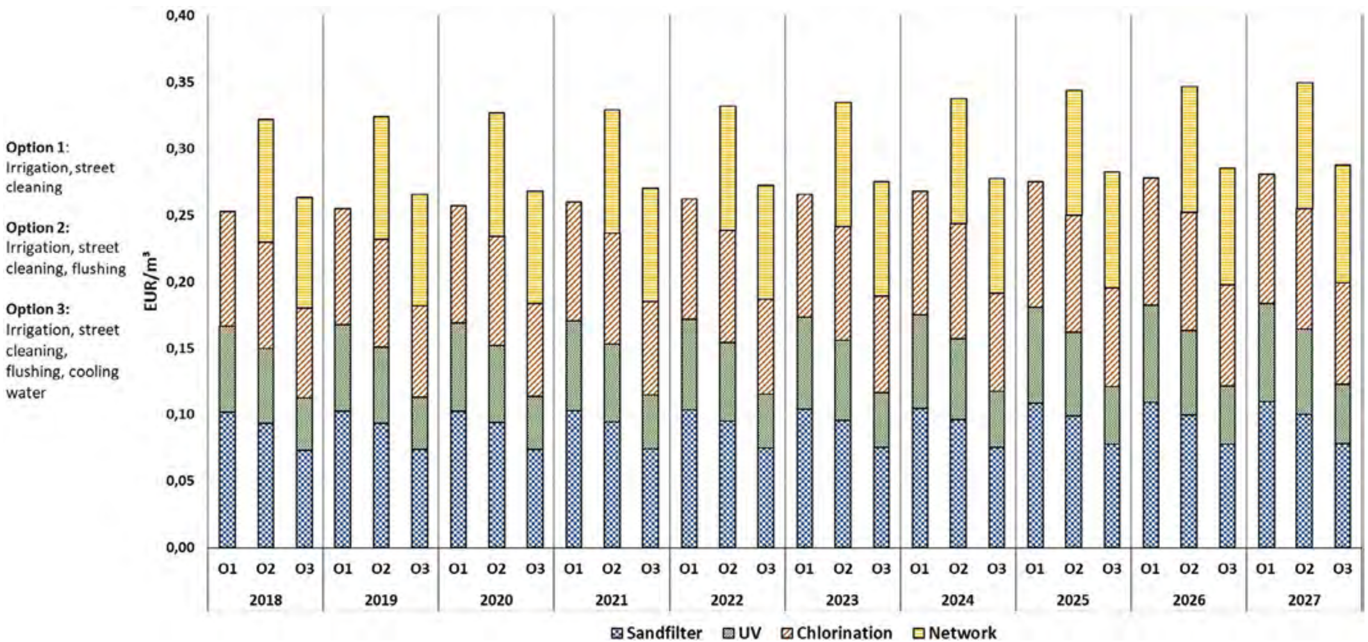

Fig. 10 Cost per cubic meter reuse water in WaRelp reuse option over 10 years.

with no further treatment. This fee may vary according to local conditions and state regulations. Depending on the duration of the permit renewals are necessary and planning security may be limited as the regulating authority may alter the conditions or volumes of abstraction (e.g. due to water stress). Under certain conditions river water needs to be decarbonized at a cost of 0.46 €/m^3 (ecoinvent v3.4) which is higher than the calculated price for the reuse plant water. Besides the extraction from a river, tap water with a queried industry price of 1.35 €/m^3. Furthermore, the wastewater handling costs and public wastewater discharge fee can be saved in case of water reuse.

Further positive effects of reuse are autonomy gain including planning security and independence from external providers and public authorities (regulators, supervisory bodies etc.) responsible for water governance at local level as mentioned in Sections 6.1 and 6.2. A possible positive environmental impact can be part of the companies' sustainability strategy and used for an eco-friendly image. Reuse can be driven by political decisions for example to promote economic development and job creation in water stressed regions.

Reuse can have positive effects for Industrial Parks but cost and benefits must be taken into account and final decisions are based on individual opinions of the industries and IPs. They should not be "pushed through" disregarding costs as described in chapter 12.2.

6.4 Case study IV: Improving water governance through ICT tools and economic incentives in South Africa

6.4.1 Initial situation and problem statement

The more general topic of water governance is illustrated by a case study from South Africa. Water governance and institutional frameworks play an important role for sustainable resource management. Water reuse itself is not considered in this study, but the lessons learnt from governance failure and ways to bridge the implementation gap between national institutional frameworks and local requirements can be easily transferred to reuse schemes and institutional setups for reuse facilities.

South Africa has ambitious water-related development goals (e.g. National Development Plan 2030) which are in line with the Sustainable Development Goals (SDGs)[47] or even surpass them. The country has established a highly ambitious and worldwide-acknowledged body of water legislation, but is struggling with the implementation of national legal regulations to meet the challenges on local level.[48] The continuing challenges to establish catchment management agencies (CMAs) according to the National Water Act[49] highlight these problems. This implementation gap between macro level (legislation/institutional framework) and micro level (local water management institutions and decision makers) is well documented[50] and results in water crisis, deterioration of resources, collapsing infrastructure, substandard services etc. These problems are amplified by increasing water demand and impacts of climate change.

Based on the research project iWaGSS (integrated Water Governance Support System) funded by the German Federal Ministry of Education and Research (BMBF) in the Olifants River Catchment, information and communications technology (ICT) based governance tools and economic measures are developed to bridge the implementation gap and improve water governance on micro (local) level.[51]

The Lower Olifants sub-catchment in South Africa has been selected as the primary demonstration area including the Phalaborwa pilot zone. The development of the region in terms of its ecological diversity and sustainability as well as economic progress and social stability is particularly vulnerable to water-related problems, including transboundary water issues. Water uses and economic activity in the Olifants basin are diverse and range from mining, power generation, metallurgic industries, irrigation, subsistence agriculture and ecotourism. The water resources of the Olifants River system are critically stressed in respect of both water quantity and quality.[52] While water management problems in the headwaters of the basin are relatively well understood (e.g. acid mine drainage (AMD) and stressed municipal wastewater treatment systems), these issues have historically had less focus in the lower part of the basin within the Lowveld region. The Lower Olifants sub-catchment is part of the UNESCO Kruger to Canyons Biosphere Reserve. This region, which includes the world renowned Kruger National Park (KNP), rural and peri-urban areas, copper and phosphate mining, subsistence and commercial farming, receives all the consequent pressures from upstream parts of the basin. The water quality of the lower Olifants River is influenced, inter alia, by return flows from mining and agriculture, for example in the Ga-Selati River.

Thus, the chosen area can be seen as representative for other basins and should be appropriate to proof scalability and transfer of research and innovation results to other regions.

6.4.2 Objective

Previous research in the Olifants catchment has shown that there is—broadly spoken—no lack of legal institutions or water resources, but a lack

Fig. 11 Real-time water quality monitoring including sediment samplers and sensors for toxicity monitoring, pH. Conductivity and additional parameters.

of effective governance systems and efficient management practices.[53] Water scarcity is rather an indication of insufficient water management and governance failure than a root cause of the water-related problems.[31] The iWaGSS real-time water management system links different tools and methods (risk assessment, surface water modeling, real-time water quality monitoring (Fig. 11) and additional data) in a single data management and decision support system to provide reliable information for water managers and stakeholders. The system is currently tested in the South African pilot zone.

The national Department of Water and Sanitation and its regional branches do not have the necessary resources and capacity to compensate for the missing CMAs. In certain cases, the implementation gap and non-functional (or missing) institutions lead to informal institutions, e.g. user forums and (informal) feedback loops of self-organization and self-regulation[53] taking over administrative and management functions to fill some of the gaps. Main actors are for example civil society organizations, conservation and research organizations, representatives of industry, agriculture and tourism, and NGOs. Although these informal institutions act without (or beyond) their legal mandate, have no or limited enforcement capacities and often lack resources and information, they are an integral part of the so called "management in the muddled middle" between the rules-in-form of governance and the rules-in-use on micro level.[50]

Main output, besides management support and planning scenarios, is access to free and reliable data for all stakeholders and increased transparency that will help (a) to improve the (informal) management of the water resources and (b) to hold responsible public servants and managers to account. Especially where governance institutions are not established respectively not working properly—the governance principles accountability and responsibility are not met—participation and transparency are key factors to improve resource management and water governance.[54]

To overcome the challenges of aging and collapsing infrastructure and substandard services, accompanying (financial) incentives and economic aspects have to be taken into account. Main goal is to improve water utility management and to increase service coverage. This includes sustainable financing mechanisms (e.g. hybrid finance and results-based financing) and professionalization of services.

6.4.3 Methodology

The iWaGSS system includes a real-time water management system basing on a network of water quality monitoring stations, surface water modeling (hydrodynamic river modeling and reservoir modeling including sedimentation) and risk-assessment tools (Fig. 12). The data is processed by a data-management system and can be displayed in a web-based GIS-portal. The system provides reliable and easy-accessible information for all interested parties (e.g. government institutions, NGOs, water users, stakeholders, researchers). The use of ICT tools links real-time water quality data with flow rates from the hydrodynamic model in a single application to generate scenarios for resource management. It is possible to track back potential sources of pollution and to identify high priority areas for future management measures.

In the absence of formal institutions respectively in a situation of governance failure, the iWaGSS real-time water management system provides

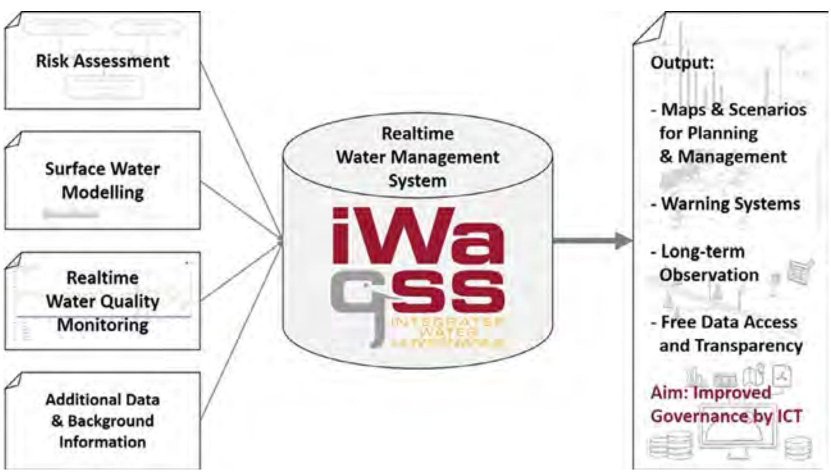

Fig. 12 Components of the iWaGSS real-time water management system.

application-oriented data and information to improve water governance and to increase resource management efficiency. The system complies with the OECD principle of efficient water governance: "Produce, update, and share timely, consistent, comparable and policy-relevant water and water-related data and information, and use it to guide, assess and improve water policy."[55]

A second pillar of the case study are economic measures to improve water governance and management. Economic studies on water efficiency, ecosystem goods and services and cost-benefit analysis are combined with financing mechanisms and operational concepts to improve the performance levels in water and sanitation services and in water resources management to face growing challenges like water scarcity and pollution. Economic incentives and financing mechanisms have a significant influence on how water and wastewater facilities are designed, built and operated.

To avoid mal-functioning facilities and collapsing infrastructure and to improve water-related services, result-based elements are needed that incentivize the delivery of defined outputs upon verification of the delivery of the agreed-upon result.[56] Furthermore, the lack of public sector funds, especially in developing countries, is a huge challenge to achieve the SDGs. Sound financial arrangements are important to ensure effective implementation and a lasting, sustainable success: "Finance and good water governance are inextricably linked."[57] The authors have developed a sustainable water financing approach to link funding and interventions to results, and to improve the effectiveness and efficiency of resource management measures.[30] Sustainable water financing includes hybrid or blended finance[58] to attract commercial funding for necessary water-related investments. Trying to integrate O&M and result-based elements into sustainable water financing concepts without shifting risks to the state through state guarantees is a matter of change management in water sector, which is mainly driven by public funds and donor money. According to the OECD principles of water governance, the sustainable water finance concept helps to mobilize water finance and to efficiently allocate financial resources.[55]

6.4.4 Results and conclusion

Water problems are solved neither by legal frameworks or government decision on macro level nor by pure market allocation.[59] Sustainable resources management requires the application of good governance on local level. To transfer legal requirements from the macro level of national legislation (rules-in-form) into operational management on micro level (rules-in-use), it is necessary to both provide relevant data and information to the affected actors and stakeholders, and to allocate the necessary (financial) resources in an effective and efficient manner. ICT tools and economic incentives play an important role to improve water governance.

These lessons learnt from water resources management should be considered for the design and setup of water reuse regulations and the operation of reuse facilities. Water reuse has a huge potential to mitigate water stress, but it is an indispensable prerequisite to base it on viable financing mechanisms and operational concepts incorporated into transparent governance institutions.

7. Final conclusion

Water reuse offers promising opportunities to reduce water stress and to increase available water resources for different purposes ranging from agricultural reuse, industrial process water to direct potable reuse. Water reuse requires tailored solution for each specific application, especially the "Seven Sins in Local Water Management" must be avoided. Adapted financial models and professional O&M concepts taking into account local requirements and available funds and technologies are essential preconditions for successful implementation of reuse schemes as shown in the case studies. These reuse schemes have to be embedded into sound governance structures to allow for efficient and sustainable use of the resources.

Acknowledgments

The authors would like to express their gratitude to the BMBF for the financial funding of the research projects WaReIp (grant no. 02WAV1409), EPoNa (grant no. FKZ 02WAV1401C) and iWaGSS (grant no. 02WGR1424), to the industrial partners for their financial and technical input and to the experts and partners in Germany, Namibia, South Africa, Vietnam and China for their intellectual support and contribution.

References

1. Wautelet T. *The concept of circular economy: its origins and its evolution*. IWA network org; 2018. https://doi.org/10.13140/RG.2.2.17021.87523.
2. Nolasco D, Rodriguez D, Serrano H, Delgado A, Saltiel G. *The linear to circular shift for wastewater in Latin America—the source*. https://www.thesourcemagazine.org/the-linear-to-circular-shift-for-wastewater-in-latin-america/?utm_source=IWA-NETWORK&utm_campaign=4d90499b91-EMAIL_CAMPAIGN_2020_05_19_08_56&utm_medium=email&utm_term=0_c457ab9803-4d90499b91-159872613; 2020. Accessed 26 May 2020.

3. Rudolph K-U, Kalinowski-Gausepohl A. *Solutions for Urban water efficiency [Presentation]*. Frankfurt, Germany; 15th May 2016.
4. Rudolph K-U. Project economics of water reuse in context to IWRM—with cases from Africa, Asia, Europe. In: International Water Association, editor. *9th IWA International Conference and Exhibition on Water Reuse; 27th–31st October 2013; Windhoek, Namibia*; 2013. p. 81–2.
5. Branch AD, Robillot C, Le-Clech P. Facilitating adoption of MBR for water reuse by improved risk management and development of better guidance. In: International Water Association, editor. *Book of abstracts IWA water reuse 2019; 16th–20th June 2019; Berlin, Germany*; 2019. p. 370–1.
6. Döpkens E, Bernhardt D, Lebek M. ZLD installations in India for F&B, chemistry and metal processing. In: International Water Association, editor. *Book of abstracts IWA water reuse 2019; 16th–20th June 2019; Berlin, Germany*; 2019. p. 598–603.
7. Lahnsteiner J, Andrade P, Mittal R. Industrial water reclamation and reuse in India. In: International Water Association, editor. *Book of abstracts IWA water reuse 2019; 16th–20th June 2019; Berlin, Germany*; 2019. p. 260–4.
8. Billenkamp E. Up to 100% reuse: zero liquid discharge versus productionintegrated water management. In: International Water Association, editor. *Book of abstracts IWA water reuse 2019; 16th - 20th June 2019; Berlin, Germany*; 2019. p. 604–5.
9. Rudolph K-U, Harbach M. *GreenTech—Chancen und Herausforderungen für die Umweltindustrien am Beispiel Wasser [Presentation]*. Munich, Germany; 28th May 2010; 2010.
10. van Rensburg P. *50 years of direct potable water reuse [presentation]*. Namibia: City of Windhoek; 2018. Windhoek, Namibia; October 2018.
11. Du Pisani P. *Outsourcing the operation and maintenance of the plant*. Namibia: City of Windhoek; 2018.
12. Rudolph K, Schafer D. *Survey Report for BMBF on 'AWS—alternative water systems'*. KIT project agency under BMBF, The German Fed Ministry of Education and Research; 2002.
13. McKenzie R, Hamilton S. *Getting back to basics with water loss management*. Water21; 201433–6.
14. Aayog NITI. *Composite water management index: a tool for water management*. 2018.
15. Grey D, Sadoff C. *Water for growth and development*. Mexico: Mexico City; 2006.
16. Nauges C, Whittington D. Estimation of water demand in developing countries: an overview. *World Bank Res Obs* 2010;**25**:263–94. https://doi.org/10.1093/wbro/lkp016.
17. Zetland D, Glasson C. A global survey of urban water tariffs: are they sustainable, efficient and fair? *Int J Water Resour Dev* 2013;**29**:327–42. https://doi.org/10.1080/07900627.2012.721672.
18. Bruinette K, Claassens T. A holistic approach in the analysis of and turn-around strategies for municipal water supply systems: the perspectives of a financier. *IMIESA* 2016;**41**:17–20.
19. Rudolph K-U, Klein G. Water loss reduction—economic gains. In: Sewilam H, Rudolph K-U, editors. *Capacity development for drinking water loss reduction: challenges and experiences*. Bonn, Germany: UN-Water Decade Programme on Capacity Development United Nations University; 2011. p. 115–30.
20. Bombeck M. *Allokation von Wasserressourcen durch Integration ökonomischer Aspekte im IWRM am Beispiel des Einzugsgebietes "Mittlerer Olifants", Südafrika [Dissertation]*. Bochum, Germany: Ruhr-Universität Bochum; 2013.
21. Sousa-Zomer TT, Miguel C, Paulo A. Sustainable business models as an innovation strategy in the water sector: an empirical investigation of a sustainable product-service system. *J Clean Prod* 2018;**171**:119–29. https://doi.org/10.1016/j.jclepro.2016.07.063.

22. Strömer K. *Development of a sustainable business model for water utilities in India and other emerging markets [dissertation]*. Witten, Germany: Universität Witten/Herdecke; 2020.
23. Rogers P, de Silva R, Bhatia R. Water is an economic good: how to use prices to promote equity, efficiency, and sustainability. *Water Policy* 2002;**4**:1–17. https://doi.org/10.1016/S1366-7017(02)00004-1.
24. Whittington D, Hanemann WM, Sadoff C, Jeuland M. *The challenge of improving water and sanitation services in less developed countries*. **4**:FNT in Microeconomics; 2008469–609. https://doi.org/10.1561/0700000030.
25. Satterthwaite D. Missing the millennium development goal targets for water and sanitation in urban areas. *Environ Urban* 2016;**28**:99–118. https://doi.org/10.1177/0956247816628435.
26. Schuster-Wallace CJ, Sandford R. *Water in the World we want: catalysing National water-related sustainable development*. Hamilton, ON: United Nations University. Institute for Water, Environment and Health; 2015.
27. Aggarwal V, Maurya N, Jain G. Pricing urban water supply. *Environ Urban ASIA* 2013;**4**:221–41. https://doi.org/10.1177/0975425313477768.
28. OECD—Organisation for Economic Co-operation and Development. *OECD DAC blended finance principles*. https://www.oecd.org/dac/financing-sustainable-development/development-finance-topics/OECD-Blended-Finance-Principles.pdf; 2018. Accessed 30 Oct 2018.
29. Lewis EW, Staddon C, Sirunda J. Urban water management challenges and achievements in Windhoek, Namibia. *Water Pract Technol* 2019;**14**:703–13. https://doi.org/10.2166/wpt.2019.055.
30. Hilbig J, Rudolph K-U. Sustainable water financing and lean cost approaches as essentials for integrated water resources management and water governance: lessons learnt from the southern African context. *Water Supply* 2019;**19**:536–44. https://doi.org/10.2166/ws.2018.099.
31. Kluge T, Polak M. Water supply infrastructure and sanitation in Central-Northern Namibia. In: Liehr S, Kramm J, Jokisch A, Müller K, editors. *Integrated water resources management in water-scarce regions: water harvesting, groundwater desalination and water reuse in Namibia*. London: IWA Publishing; 2018. p. 19–22.
32. Environmental Protection Agency (USA). *Principles of design and operations of wastewater treatment pond systems for plant operators, engineers, and managers*. Cincinnati, Ohio, USA, 2011.
33. Angula MN, Kaundjua MB. The changing climate and human vulnerability in north-Central Namibia. *Jamba* 2016;**8**:200. https://doi.org/10.4102/jamba.v8i2.200.
34. Mara D, Pearson H, Orgaui J, Arridge H, Silva SA. *Development of a new approachto waste stabilizationpond design*. U.K.: Leeds; 2001.
35. Short MD. *Advanced techniques for the upgrading of waste stabilisation pond effluent: rock filtration; duckweed; and attached-growth media*. Adelaide, Australia: [Dissertation] Flinders University; 2008.
36. von Sperling M. *Waste stabilisation ponds*. London: IWA Publishing; 2007.
37. Grobosch M. *Grundwasser und Nachhaltigkeit—Zur Allokation von Wasser über Märkte*. 2003.
38. Bauer S, Dell A, Behnisch J, Chen H, Bi X, Nguyen VA, et al. Sustainable water-reuse concept for industrial park developments in Southeast Asia. *Asian Water* 2018;**34**:24–7.
39. Veilleux JC. Water conflict case study—Ethiopia's grand renaissance dam: turning from conflict to cooperation. In: *Earth systems and environmental sciences*. Elsevier; 2013. https://doi.org/10.1016/B978-0-12-409548-9.09445-8.
40. Bender S, Butts M, Hagemann S, Smith M, Vereecken H, Wendland F. *Der Einfluss des Klimawandels auf die terrestrischen Wassersysteme in Deutschland: Eine Analyse ausgesuchter Studien der Jahre 2009 bis 2013. Hamburg, Germany*. 2017.

41. Vietnam Environment Administration, The Science and technology Administration, and The Legal Department. National technical regulation on industrial wastewater. In: *QCVN 40:2011/BTNMT*, 28th December, 2011.
42. Bauer S, Dell A, Behnisch J, Linke HJ, Wagner M. Sustainability requirements of wastewater management concepts for new industrial park developments in water-stressed regions, In: International Water Association, editor. *Book of abstracts IWA water reuse 2019; 16th–20th June 2019; Berlin, Germany*; 2019. p. 274–80.
43. Kreuter S, Rudolph K-U. *Best practice guide for the development of integrated wastewater concepts for industrial zones in tropical areas*. Germany: Witten; 2016.
44. Bischoff A. *Desinfektion von behandeltem Abwasser—Vergleich verschiedener Desinfektionsverfahren [Dissertation]*. Darmstadt: Technische Universität Darmstadt; 2013.
45. Hunziker-Betatech. *Massnahmen in ARA zur weitergehenden Elimination von Mikroverunreinigungen—Kostenstudie. Winterthur, Switzerland*. 2008, 22.10.
46. Elefritz RA. Comparison of alternate methods of disinfection for reclaim effluents. *Florida Water Res J* 2000;19–29.
47. UN—United Nations. *Transforming our world. The 2030 Agenda for sustainable development*. 2015.
48. Herrfahrdt-Pähle E. *Introducing catchment management: the case of South Africa*. Bonn: Dt. Inst. für Entwicklungspolitik; 2010.
49. RSA—Republic of South Africa. National Water Act. Act No. 36 of 1998. 1998.
50. Clifford-Holmes JK, Palmer CG, de Wet CJ, Slinger JH. Operational manifestations of institutional dysfunction in post-apartheid South Africa. *Water Policy* 2016;**18**:998–1014. https://doi.org/10.2166/wp.2016.211.
51. Rudolph K-U, Hilbig J. ICT-gestütztes Wassergovernancesystem für Regionen mit überbeanspruchten Wasserressourcen in Afrika und weltweit. In: *53.ESSENER TAGUNG für Wasserwirtschaft—Wasser in einer sich verändernden Welt: Gewässerschutz—Wasser—Abwasser. Aachen, Germany*; 2020.
52. DWS—Department of Water and Sanitation. Development of an integrated water quality management plan for the Olifants river system. In: *Report No.9—Lower Olifants Sub-catchment Plan*; 2018.
53. Pollard S, Du Toit D, Biggs H. River management under transformation: the emergence of strategic adaptive management of river systems in the Kruger National Park. *Koedoe* 2011;**53**:59. https://doi.org/10.4102/koedoe.v53i2.1011.
54. Rogers P, Hall AW. Effective water governance. In: *Technical committee background papers No. 7. Stockholm, Sweden*; 2003.
55. OECD—Organisation for Economic Co-operation and Development. *OECD Principles on Water Governance*. http://www.oecd.org/cfe/regionaldevelopment/OECD-Principles-on-Water-Governance.pdf; 2015. Accessed 8 Jun 2020.
56. Musgrove P. *Financial and other rewards for good performance or results: a guided tour of concepts and terms and a short glossary*. Washington DC, USA, World Bank; 2011.
57. Grau G, Hall A. Unlocking finance for water security: building capacity and raising awareness. In: *Report to European Union Water Initiative. Stockholm, Sweden*; 2012.
58. OECD – Organisation for Economic Co-operation and Development. *Making blended finance work for SDG 6*. OECD; 2019.
59. Grigg NS. *Governance and management for sustainable water systems*. London, UK: IWA Publishing; 2011.