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DECISION SUPPORT TOOL FOR WATER RECLAMATION BEYOND TECHNICAL CONSIDERATIONS – EGYPTIAN, MOROCCAN AND TUNISIAN CASE STUDIES

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Data accessibility statement

Following data, associated metadata and calculation tools are available on the Zenodo repository:

Decision Support Tool (DST):

1. **DST and Handbook, version 2.0**: Oertlé, Emmanuel. (2020). Poseidon 2.0 - Decision Support Tool for Water Reuse (Microsoft Excel) and Handbook (Version 2.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.3755380
2. **DST and Handbook, version 1.1.1**: Oertlé, Emmanuel. (2018, December 5). Poseidon - Decision Support Tool for Water Reuse (Microsoft Excel) and Handbook (Version 1.1.1). Zenodo. http://doi.org/10.5281/zenodo.3341573

Former publication describing the method of the DST in details:

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Background Datasets:

4. **Wastewater Treatment Unit Processes Datasets**: Oertlé, Emmanuel. (2018). Wastewater Treatment Unit Processes Datasets: Pollutant removal efficiencies, evaluation criteria and cost estimations (Version 1.0.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.1247434
5. **Treatment Trains for Water Reclamation**: Oertlé, Emmanuel. (2018). Treatment Trains for Water Reclamation (Dataset) (Version 1.0.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.1972627

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ABSTRACT

While the Middle East and North African region is facing challenges to sustain water security, water reclamation has received increasing consideration as a favourable mitigating solution. Despite the availability of adequate technologies; economic, political, legal, social, and environmental constraints often hamper stakeholders and especially decision makers to exploit the existing potential into implementation of solutions. In this paper, a comprehensive assessment for water reclamation and reuse was developed. This assessment consists of four objectives, namely A) applying a decision-support tool (DST) for water reclamation potential for municipal wastewater, B) applying a DST for simulating and estimating lifecycle costs of project-related technologies for water reclamation (municipal and industrial wastewater, drainage canal water), C) assessing the national-level conditions for water reuse with a multi-criteria decision analysis, and D) establishing exemplary strategies, barriers and measures for water reuse. This analysis considers six thematic subjects: policy and institution, economy, society, water management, legislation, and environment. The assessment was applied to food and non-food crop irrigation in Egyptian, Moroccan, and Tunisian case studies. For all defined case studies, adapted treatment trains that could treat wastewater to the desired quality at reasonable costs were identified and are presented in this paper. The results show that technological options are available for water reuse, but the concept is not widely implemented in Egypt, Morocco, and Tunisia. This paper identifies key barriers and drivers for the implementation of water reclamation for irrigation. In particular, the considered countries show different characteristics regarding efficient water management, water pricing, subsidies and wastewater tariffs, implementation of monitoring and reporting systems or legal aspects related to the use of reclaimed water for food crop irrigation. Further exploration of case studies on high potential water reuse and financially affordable wastewater reclamation, particularly case studies that explore the impacts of policies and practices across countries, would be useful to help the Middle East and North African region improve its water security situation.

Keywords:

Water reuse (WR); wastewater recycling; water reclamation; decision support tool (DST); water resources management (WRM), multi-criteria analysis (MCA); Middle East and North Africa (MENA)

Introduction

While the Middle East and North African region is facing challenges to sustain water security, water reclamation has received increasing consideration as a favourable mitigating solution (World Resources Institute 2019). Water or wastewater reclamation is the process of treating wastewater to turn it into water that can be used for beneficial purposes. Water reuse refers to the beneficial use of reclaimed water (the 'fit-for-purpose' concept) (WWDAP – United Nations World Water Assessment Programme / 2017). The main incentive for water reclamation is the use of treated wastewater as a water resource for beneficial purposes, because it can reduce pressure on fresh surface or groundwater resources. A second incentive is that wastewater is not discharged to receiving environments, thus reducing pollution of water bodies.

In this paper, an assessment of water reclamation and reuse was developed. This assessment had four objectives, namely A) apply a decision-support tool (DST) to assess water reclamation potential for municipal wastewater, B) estimate lifecycle costs of project-related technologies for water reclamation (municipal and industrial wastewater, drainage canal water), C) assess the national-level conditions for water reuse with a multi-criteria decision analysis (MCA) to identify drivers and barriers, and D) establish exemplary strategies for, barriers to and measures of water reuse. This MCA consists of six thematic subjects: policy and institution, economy, society, water management, legislation, and environment. Wastewater reclamation is defined as cleaning of wastewater to a purity that can be used for a specified purpose(s). Wastewater reuse is defined as beneficial use of treated wastewater (Asano et al. 2007).

This analysis was applied to three countries in the Middle East and North Africa (MENA): Egypt, Tunisia, and Morocco. Safeguarding water security in these countries is challenging and each country faces unique water management concerns.

Egypt has been suffering from severe water scarcity in recent years. Renewable freshwater resources include only 20 cubic meters per person per year, which places it at 176 out of 179 nations according to AQUASTAT, the Food and Agriculture Organization of the United Nations global information system on water resources and agricultural water management (www.fao.org/aquastat/en/). The country relies heavily on the Nile River as its main source of water. Egypt is already below the United Nations' water poverty threshold, and by 2025 the UN predicts, it will be approaching a state of "absolute water crisis." (Eco Mena, 2017; The Guardian, 2015).

Tunisia ranks 159 out of 179 nations in AQUASTAT (379 cubic meters per person per year), with water resources characterized by scarcity and periodic droughts of various lengths. The most common drought years have rainfall deficits ranging from 30% to 50%. Over the last decade, Tunisia has achieved considerable success in expanding access to both water and sanitation services, but challenges remain (Ameur 2007; World Bank 2014).

At 848 cubic meters per person per year, Morocco ranks 143 out of 179 nations in AQUASTAT. Although Morocco is far from the ‘extremely high’ ratio of water withdrawal to supply that occurs in many Middle Eastern countries, the kingdom is still among the 45 countries facing water scarcity. It is confronted with dwindling groundwater reserves and a strong dependence on rain-fed agriculture. Cultivable land is compromised by water shortages and soil erosion (Morocco World News 2017; USAID 2017; Espace Associatif 2012). To overcome this problem, several laws and regulations were adapted to improve the availability and quality of water resources (Choukr-allah et al. 2017).

Materials and Methods

Assessment, simulation, and calculation of lifecycle costs for wastewater reclamation (Objectives A and B)

Local adaptation of a decision support tool for water reclamation

The selected DST has been developed especially for this study and is published in an open access repository together with a handbook (Oertlé 2020). The DST’s purpose is to identify technology options that can treat wastewater to the desired quality for several representative case studies (Figure 1). The user provides information about the wastewater to be reclaimed (i.e. quality parameters and quantity), the desired reclaimed water quality (i.e. from a set of national regulations and international guidelines), and local cost information. The DST recommends top-ranking technology options from a database of benchmark treatment trains (series of unit processes) based on pollutant removal efficiencies, lifecycle treatment costs, or a user-defined weighting profile. The DST currently includes 37 unit processes that can be combined into 70 benchmark treatment trains (Oertlé et al. 2019). For this research, the DST has been adapted to specific cases of Egypt, Morocco, and Tunisia, by including data and information specific to those countries in the tool. Data were collected in a literature research on typical wastewater qualities, national regulations on water quality requirements for the compliance with different types of reuse, and local cost factors (Table 2, supplementary materials). Such factors include energy cost, personal cost and discount rates (i.e., interest minus inflation rate). The whole set of collected data and the resulting DST is presented in supplementary materials IV of this paper and has been uploaded to an open access repository.

To conduct a generic assessment for the three countries, typical wastewater quality classes in the Mediterranean and African Countries (MAC) have been established based on collected local data complemented with values from literature (Asano, Burton, and Leverenz 2007) (Table1, supplementary materials). Specific contaminants from industrial wastewaters are not included in this assessment (e.g., polyphenols, fungicides, dyes) but should be considered when designing treatment trains. Furthermore, national regulations for wastewater reuse and irrigation are considered together with ISO guidelines, as the water quality targets to be achieved by the reclaimed water.

Definition of representative case studies

Assessment of national-level conditions for water reuse (Objective C)

A political, economic, social, technology, legal, and environmental (PESTLE) approach (Kolios et al.. 2013) was employed to guarantee that all involved disciplines were considered. Each discipline is represented by two to four key questions. These in turn are underpinned by one quantitative or semi-quantitative indicator (Table 2 for overview; Table 10, supplementary materials for details). Indicator selection was based on the work of Esteve Bengoehea et al. (2017) and expert face-to-face discussions (Kerr and Tindale 2011). These indicators provide an indicative general understanding of the current situation of water reuse in Egypt, Tunisia, and Morocco and are selected on the basis of existing indicators, which were scanned from major water reuse studies and recognised databases (Esteve Bengoehea et al. (2017); Snethlage et al. 2018; FAO - UN Food and Agriculture Organisation 2016).

The indicator results were classified as 'lower' = 1, 'moderate' = 2, and 'higher' = 3 (Table 11, supplementary materials). For the indicator results, a linear ranking was applied if possible. This included for 'lower': 0 – 33.3%, 'moderate': >33.3 – 66.6%, and 'higher': 66.6 – 100% based on (BGS 2015; Oakdene Hollins 2008). The terms 'lower' and 'higher' were applied, because the connotation of these terms better describe the involved data uncertainty than the connotation of 'low' and 'high' (Mueller 2018).

Four indicators were scored for the assessment of the countries Egypt, Tunisia, and Morocco in this study only. Therefore, for each of these four indicators, the maximum water reuse level was assigned as the maximum value. The minimum water reuse level was assigned to the minimum value. In between these maxima and minima, a linear ranking of thirds was determined. This was applied to the indicators 'Water pricing for agriculture,' 'Percent of annual produced water volume per total population in a country,' and 'Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops).' This last indicator is being established in ongoing research activities. Currently, we assumed that the indicators are equally weighted; this assumption will be tested in our future research activities.

Establishment of exemplary strategies, barriers and measures for water reuse (Objective D)

Exemplary basin-scale and national wastewater management strategies were established including economic instruments for Egypt, Morocco and Tunisia. The exemplary strategies were built based on the top-ranking options from the DST based on the treatment costs and from the MADFORWATER project pilot schemes. These options and corresponding technologies are complemented by the results of the MCA that identifies barriers, drivers and measures recommended to foster the implementation of sound solutions for water reuse in the region.

Results

A. Assessment of potential for municipal wastewater

For every considered case study, treatment trains that comply with the water quality requirements of the ISO guidelines were identified (Table 3). For all considered case studies, the results include the top-ranking option considering the cost (C1) and the top-ranking option considering the weighted evaluation factors (W1). Those results are a good indication of the potential for water reuse and possible treatment trains. However, this is a simplified pre-feasibility assessment with limitations, as it is only based on the parameters defined in the DST. Additional parameters currently not considered should be included in future feasibility studies.

Nevertheless, the results show that there are available technologies that could treat typical Egyptian, Moroccan, and Tunisian municipal wastewater and secondary effluent of municipal wastewater treatment plants to fully comply with international standards. Identified options ranked according to costs have a lifecycle treatment cost ranging between 0.22-0.97 USD per cubic meter for reclaimed water. Thus, these options provide reclaimed water at an affordable cost.

Identified treatment trains presented in Table 3 are based on a list of 70 treatment trains included in the DST (Oertlé 2018). These are mostly based on typical benchmark technologies and on case studies from around the world. Results show that five treatment trains highly ranked in the assessment have a high potential for the defined case studies:

Title 22: Belgium: Example from Belgium re-using water to produce cooling water for industrial purposes. A pharmaceutical company (Tienen) makes use of treated municipal wastewater for cooling water. Thereby, secondary treated effluent is ozonated for disinfection. If the amount of reclaimed wastewater is too low or temperature is too high, it is mixed with groundwater before usage. The wastewater treatment plant (WWTP) consists of a low loaded activated sludge system with enhanced biological phosphorous removal (Davide Bixio, Wintgens, and Bixio 2006a).

Only disinfection Benchmark Technology: Many examples are available all over Europe. Conventional wastewater treatment, followed by chlorination, enabling the reuse of the treated water for irrigation under restricted conditions (Van Der Graaf et al. 2005).

Lagooning Australia: Example from Australia of water reclamation for horticultural (unrestricted) irrigation. WWTP effluents are reused for horticultural irrigation. Main irrigated crops are root and salad crops, brassicas, grapes and olives (= unrestricted irrigation). Sewage is treated in the WWTP by activated sludge process. The effluents from secondary treatment are then held in shallow aeration lagoons for a minimum of 6 weeks, before passing through a dissolved air flotation and dual media filtration process at the water reclamation plant. Here, the effluents discharge to balancing storage via a chlorinator before being pumped into the pipeline for horticultural irrigation distribution (Davide Bixio, Wintgens, and Bixio 2006b).

Wetlands Spain: Example from Spain with the goals to feed water of sufficient quality to the Cortalet lagoon in a Natural Reserve and to stimulate the recovery and establishment of local flora and fauna. The WWTP is of the extended aeration type and *consists* of a mechanical pre-treatment step and then two parallel treatment lines, each comprising a biological reactor, a clarifier and three effluent polishing ponds. There is also a chemical treatment for phosphorus removal. Further treatment is achieved by means of a wetland system (3 parallel cells) (Davide Bixio, Wintgens, and Bixio 2006b).

Wetlands USA: Treated effluent from Arcata WWTP (California, USA), is *discharged* into ‘enhancement wetlands’, which are part of the Arcata Marsh and Wildlife Sanctuary. The first treatment steps at the Arcata WWTP consist of bar screens, a grit chamber and two settling tanks for primary treatment. Secondary and partial tertiary treatment is accomplished by two oxidation ponds followed by three parallel free water surface (FWS) wetlands that were constructed in 1985. After chlorination and de-chlorination, part of the wastewater is released while another part flows into three ‘enhancement FWS wetlands.’ The ‘enhancement wetlands’ together with some additional landscape features, are referred to as the Arcata Marsh and Wildlife Sanctuary (Davide Bixio, Wintgens, and Bixio 2006b).

For the national regulations of Egypt, Morocco and Tunisia, treatment trains were also identified for all simulated case studies (Table 4). If limitations also apply to the results, they show that there are available technologies that could treat typical Egyptian, Moroccan, and Tunisian municipal wastewater and secondary effluent of municipal wastewater treatment plants to comply with national regulations. Identified options ranked on cost have a lifecycle treatment cost ranging between 0.16-0.80 USD per cubic meter for reclaimed water. Thus these options provide reclaimed water at an affordable cost.

Identified treatment trains presented in Table 4 show that four treatment trains in addition to the ones defined in section have a high potential for the defined case studies:

- *Wetlands, Nicaragua*: Constructed wetland in Masaya pilot plant. The system treats the domestic wastewater (100 cubic meters per day) generated by 1,000 people living in the city of Masaya, Nicaragua. The scheme comprises pre-treatment (screen and grit tank) and four constructed wetland beds fed in parallel. The area of each wetland bed is about 350 square meters, totalling 1,400 square meters. Effluent from the pilot plant in Masaya can be used for restricted irrigation (Gauss 2008).
- *Wetlands, Senegal*: Example of water reuse for agricultural purpose. The main wastewater reuse site in urban agriculture in Dakar, Senegal is Pikine. Of Pikine’s total cultivated area of approximately 120 acres (50 ha), about 40 acres (16 ha) makes use of raw wastewater for irrigation. Usually, farmers divert wastewater

from the sewage using pipes to load narrow wells located in their plot. From that well, they use water cans to irrigate crops such as lettuce, which grow rapidly. Wastewater treatment using wetlands has been introduced which showed good removals of *E. coli* and helminth eggs. The treatment lines tested used combinations of four ponds (each 2 m^3) in series: One waste stabilization pond is followed by three reed or Vetivera planted stabilization ponds with free water surface and surface water flow (US-EPA 2012).

- *Direct membrane filtration benchmark technology*: New concept, which is investigated in several places (Netherland, China, Israel). Micro- or ultrafiltration of raw wastewater followed by agricultural applications (Van Der Graaf et al. 2005).

- *Only disinfection*: Treatment train of Copiapó Wastewater Treatment Plant. Water re-use in mining industry and agriculture. The wastewater from Copiapó, Chile are directed to Copiapó WWTP, where the wastewater is subjected to a primary treatment to retain thick solids, then through a secondary treatment to carry out the oxidation of organic matter by activated sludge. The mixture flows to a separation process of solid and liquid in the clarifier, generating a sludge stream and a treated water stream. The water stream is subjected to chlorination and discharged to Copiapó river (Verzandvoort et al. 2013).

B. Simulation and lifecycle costs of MADFORWATER project treatment trains

The second objective focuses on assessing the selection of treatment trains from the MADFORWATER projects that have been simulated with the DST. The performance of those trains is not known yet, as pilots are ongoing, however, the lifecycle treatment costs have been calculated for different flow rates in the three target countries (Figure 3). Apart from the train focusing on municipal wastewater, the four other wastewater treatment trains are specifically designed for industrial wastewater (i.e. olive mill wastewater, textile wastewater, and fruit and vegetable packaging plant); and for drainage canal water, which is more specifically addressed to the Egyptian case study. In addition to lifecycle treatment costs, DST simulation provides detailed cost information for the different wastewater treatment trains that can be considered in the decision-making process.

C. *Assessment* of national-level conditions for water reuse

The scored results of the MCA are shown in Table 5, based on an investigation of different indicators (specific results of the indicators: Table 12, supplementary materials).

Tunisia shows mostly water reuse level of ‘higher’ to ‘moderate’ but ‘lower’ for the thematic subject ‘economy’. ‘Higher’ resulted, because of the key area ‘environment’ and ‘policy & institution.’ Regarding ‘environment’, the results showed a strict guidance regarding the national water reuse regulations in comparison with the international BS ISO guidelines for treated wastewater use for irrigation projects (ISO, 2015).

Morocco shows mostly a water reuse level of ‘higher’ to ‘moderate’ but ‘lower’ for the thematic subject ‘economy’ and ‘environment.’ ‘Higher’ resulted because of the thematic subject ‘society’ with the indicator ‘share of using improved sanitation services’.

Egypt shows mostly a water reuse level of ‘higher’ to intermediate values between ‘lower’ to ‘moderate’ but ‘lower’ for the thematic subject ‘environment.’ The thematic subjects 'policy & institutions' and 'society' scored 'higher.' The thematic subjects 'water management' and 'environment' scored 'lower.'

The thematic subjects 'society' and 'policy & institution' scored 'higher' to 'moderate' level of water reuse. They scored 'higher' in 8 out of 10 simulations, and 'moderate' for 2 out of 10. This indicates there are favourable condition for water reuse in these thematic subjects. The results of the thematic subjects 'economy', 'water management' and 'environmental' resulted with the most 'lower' water reuse level. This indicates the main barriers to water reuse come from these thematic subjects.

D. Establishment of exemplary strategies, barriers and measures for water reuse

With this study the exemplary strategies were established upon the top-ranking options from the DST (i.e., options selected based on cost for treating municipal wastewater and secondary effluent to comply with ISO guidelines, table 3) and from the MADFORWATER project pilot schemes. These options and corresponding technologies are complemented by the results of the MCA that identifies barriers, drivers and recommended measures to foster the implementation of water reuse in the MENA region. In Table 6, the strategies' results with costs and additional measures and barriers are presented as an overview. The detailed assessment on barriers, drivers and recommended measures can be found in the supplementary materials (Tables 13, 14 and 15, supplementary materials).

3 main types of measures could overcome identified barriers. First, price-based instruments are important to overcome the barriers. These include pricing/water tariffs, removal of subsidies or other financial assistance (e.g. assisted loans), and taxes. The underlying barrier is generally that freshwater irrigation is cheaper than

reclaimed wastewater irrigation. Second, lack of financial support programs mean that start-up costs for wastewater treatment trains are too high, so not enough water is treated. Third, non-economic instruments like education, legislation and enforcement are to promote the development of wastewater treatment capacity.

An additional key outcome of the assessment presented is the importance of the distribution costs, as demonstrated for the option **MO3**. The distribution costs were not considered for the other options, but it can be stated that judicious siting of wastewater generation, treatment and reuse locations is crucial. Ideally, reusers should be situated at a lower elevation than the source and the distance should be minimised. If reclaimed water has to be transported uphill after treatment, the transport costs can greatly exceed treatment costs (Hochstrat et al. 2007).

Conclusions

This study demonstrates the application of a decision support tool for water reuse, employing Egyptian, Moroccan and Tunisian case studies. The research compiled useful information on typical wastewater quality and current water quality regulations for water reuse. Some data gaps were identified, and missing parameters were estimated with values from case studies of other countries.

The assessment indicated high potential for water reuse in Egypt, Morocco, and particularly Tunisia. Treatment trains that could treat wastewater to the desired quality at reasonable costs ranging from 0.15 to 1.19 [USD/m^3] for flows of 10,000 [m^3/d] were identified and are presented in this paper. The results show that start-up costs are the principal barrier to water reuse. Wastewater reclamation subsidies or freshwater tariffs could help overcome the start-up cost barrier, and education could help improve the efficiency of wastewater reclamation

The assessment is a positive step in improving the understanding of wastewater reclamation and reuse, thereby creating opportunity to increase its use in the Middle East and North Africa. The assessment expands the existing DST to permit a broad, early stage assessment of local technological and economic options using available data. It could encourage jurisdictions to conduct more detailed design studies for specific locations where reclaimed water might currently be underutilized.

Future research into water reuse in the Middle East and North Africa should (i) focus on specific case studies with high potential for water reuse and (ii) identify exemplary cases to implement demonstration sites for wastewater reclamation at an affordable cost.

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Table 1: Case studies considered for the assessments A and B.

A. Municipal wastewater		**Purpose**: identify treatment trains compliant with international and national regulations
Typical municipal wastewater quality (MWW)	10,000 [m^3/d]	ISO Guidelines (16075-2:2015) Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw, Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops, and Cat. C: Agricultural irrigation of non-food crops. Egyptian, Moroccan, and Tunisian regulations for wastewater reuse.
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)	10,000 [m^3/d]	
B. Specific wastewater and corresponding treatment trains (TT)		**Purpose**: calculate lifecycle treatment costs for a selected series of unit processes
Drainage canal water (DCW-TT)	1,000 [m^3/d]	Anaerobic stabilization ponds, constructed wetland

Fruit and vegetable packaging plant (FVPWW-TT)	200 [m^3/d]	Activated sludge, flocculation, activated carbon, ultraviolet disinfection
Municipal wastewater (MWW-TT)	10,000 [m^3/d]	Trickling filter with secondary sedimentation, sedimentation without coagulant, constructed wetland, chlorine dioxide, equalization basin
Olive mill wastewater (OMW-TT)	100 [m^3/d]	Microfiltration, ion exchange
Textile wastewater (TWW-TT)	200 [m^3/d]	Flocculation, sedimentation without coagulant, low loaded activated sludge with denitrification and secondary sedimentation

Table 2: Description of the thematic subjects, key questions, quantitative and semi-quantitative indicators with possible data sources. N/Av stands for 'not available'.

Thematic subject (Ts)	Key question	Indicator	Unit	References
Economy (Ec)	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	Total official financial development assistance (gross disbursement) for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	Euro/m^3 produced wastewater	UN – SDG Indicators 6.a.1 Global Database in Esteve et al. (2017)
	-What is the level of **economic water security**?	Economic water security	N/Av (ratio of max. 20)	(Snethlage u. a. 2018)
	-What is the **water pricing for agriculture**?	Water pricing for agriculture	Euro / m^3	(Esteve et al. 2019)
Water Management (WM)	-What is the **transboundary water dependency ratio**?	Transboundary Water Bodies Dependency Ratio in the Northern African region	%	2nds Arab State of Water Report in Esteve et al. (2017)
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country	m^3/(a*inhabitants)	(Commissariat Regional au Developpement Agricole Nabeul 2016; FAO - UN Food and Agriculture Organisation 2016; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; University of Tunis El Manar 2018)

	- What is the share of **treated to produced volume** of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater	%	2nds Arab State of Water Report in Esteve et al. (2017) (Commissariat Regional au Developpement Agricole Nabeul 2016; FAO - UN Food and Agriculture Organisation 2016; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; University of Tunis El Manar 2018)
	-What is the share of **harvested irrigated crop area per cultivated area**?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)	ha	(FAO - UN Food and Agriculture Organisation 2016)
Policy and institutional (P&I)	-What is the proportion of **monitoring and reporting** systems **in comparison to other countries**?	Proportion of monitoring and reporting system between African countries reported on by country	%	(Esteve u. a. 2017)
	-What is the degree of **implementation of national monitoring and reporting** system?	Degree of implementation of national monitoring and reporting system	%	(Esteve u. a. 2017)
Legislation (L)	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	World governance index, rule of law	%	(Kaufmann u. a. 2010)
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	Compliance for food and non-food crop irrigation with reclaimed water	ranking: yes, partly, no	Own development(Mueller 2018)
Society (S) **including public involvement in the decision making processes**	-What is the degree of **implementation of equitable water and wastewater tariffs?**	Degree of implementation of equitable and efficient water supply and wastewater tariffs	%	2nds Arab State of Water Report in Esteve et al. (2017)
	-What share of population is using **improved sanitation services**?	Share of using improved sanitation services	%	UN – SDG Indicator Global Database SDG 6.2.1 in Esteve et al. (2017)
Environment (En)	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	ranking: higher, moderate, lower	Own development, and (Mueller 2018), and intended stakeholder survey by Mueller et al. (2019)
	-What is the share of **the area equipped for irrigation that has become salinized**?	Percent of area equipped for irrigation that has become salinized	%	(FAO - UN Food and Agriculture Organisation 2016)

Table 3: Top-ranking treatment trains based on cost (C1) and weights (W1) for treating municipal wastewater and secondary effluent to comply with ISO guidelines and lifecycle treatment costs in Egypt, Morocco and Tunisia.

Ranking	**Egypt** [USD/m^3]	**Morocco** [USD/m^3]	**Tunisia** [USD/m^3]
Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw			
Typical municipal wastewater quality (MWW)			
C1-‘Title 22: Belgium’	0.97	0.59	0.52
W1-‘Only disinfection Benchmark Technology’	1.19	0.68	0.65
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1-‘Lagooning: Australia’ I	0.39	0.23	0.22
W1-‘Wetlands: Spain’	1.01	0.59	0.56
Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops			
Typical municipal wastewater quality (MWW)			
C1-‘Wetlands: USA’	0.80	0.44	0.42
W1-‘Only disinfection Benchmark Technology’	1.19	0.68	0.65
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1-‘Lagooning: Australia’ I	0.39	0.23	0.22
W1-‘Wetlands: Spain’	1.01	0.59	0.56
Cat. C: Agricultural irrigation of non-food crops			
Typical municipal wastewater quality (MWW)			
C1-‘Wetlands: USA’	0.80	0.44	0.42
W1-‘Wetlands: Spain’	1.01	0.59	0.56
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1-No treatment	0.00	0.00	0.00
W1-No treatment	0.00	0.00	0.00

Table 4: Top-ranking treatment trains for treating municipal wastewater and secondary effluents to comply with Moroccan, Egyptian, and Tunisian regulations based on cost (C1) and weights (W1).

Ranking	**Cost** [USD/m^3]	**Ranking**	**Cost** [USD/m^3]
Typical municipal wastewater quality (MWW)			
Moroccan Regulation - Cat A: irrigation of crops to be eaten raw		*Moroccan Regulation - Cat B & C: irrigation of other crops*	
C1-'Wetlands: Nicaragua'	0.16	C1-'Wetlands: Nicaragua'	0.16
W1-'Wetlands: Spain'	0.59	W1-'Wetlands: Spain'	0.59
Egyptian wastewater reuse regulation - Level A: landscape irrigation in urban areas		*Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas*	
C1-'Wetlands: USA'	0.80	C1-'Lagooning: Australia I'	0.39
W1-'Only disinfection Benchmark Technology'	1.19	W1-'Wetlands: Spain'	1.01
Tunisian regulation - NT 106.03 standard: irrigation		*Tunisian regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use*	
C1-'Wetlands: Senegal'	0.37	C1-'Only disinfection: Chile'	0.52
W1-'Wetlands: Spain'	0.56	W1-'Wetlands: Spain'	0.56
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw		*Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops*	
C1-No treatment	0.00	C1-No treatment	0.00
W1-No treatment	0.00	W1-No treatment	0.00
Egyptian regulation - Level A: landscape irrigation in urban areas		*Egyptian regulation - Level B: agriculture purposes in desert areas*	
C1-'Direct membrane filtration Benchmark Technology'	0.40	C1-'Direct membrane filtration Benchmark Technology'	0.40
W1-'Wetlands: Spain'	1.01	W1-'Wetlands: Spain'	1.01
Tunisian regulation - NT 106.03 standard: irrigation		*Tunisian regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use*	
C1-'Wetlands: Nicaragua'	0.15	C1-'Wetlands: Nicaragua'	0.15
W1-'Wetlands: Spain'	0.56	W1-'Wetlands: Spain'	0.56

Table 5: The results of the national-level conditions for water reuse assessment. ‘Lower’ national-level conditions for water reuse is in red and equivalent to the score ‘1’, moderate national-level conditions for water reuse in yellow and equivalent to the score ‘2’, ‘higher’ national-level conditions for water reuse in green and equivalent to the score ‘3’. The aggregated values can in addition include ‘intermediate values between ‘1’ and ‘2’ in orange shades, and ‘2’ and ‘3’ in light green shades. ‘-‘stand for’no data available‘ or’not defined.

Ts	Key question	Indicators	Morocco		Egypt		Tunisia	
			aggregated	**detailed**	**aggregated**	**detailed**	**aggregated**	**detailed**
Ec	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	Total official financial development (gross disbursement) assistance for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	**1.3**	1	**1.3**	1	**2**	2
	-What is the level of **economic water security**?	Economic water security		2		2		3
	-What is the **water pricing for agriculture**?	Water pricing for agriculture		1		1		1
WM	-What is the **transboundary water dependency ratio**?	Transboundary Water Bodies Dependency Ratio in the Northern African region		3		1		1
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country		3		1		2
	- What is the **share of treated to produced volume** of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater	**2.5**	1	**1.3**	2	**2.5**	2
	-What is the share of **harvested irrigated crop area per cultivated area**?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)		3		1		3
P&I	-What is the **proportion of monitoring and reporting** system	Proportion of monitoring and reporting system between African	**-**	-	**2.5**	2	**3**	3

Ts	Key question	Indicators	Morocco		Egypt		Tunisia	
			aggregated	detailed	aggregated	detailed	aggregated	detailed
	in comparison to other countries?	countries reported on by country						
	-What is the degree of **implementation of national monitoring and reporting** system?	Degree of implementation of national monitoring and reporting system		-		3		3
L	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	World governance index, rule of law	**2.5**	2	**1.5**	1	**2**	2
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	Compliance for food and non-food crop irrigation with reclaimed water		3		2		2
S	-What is the degree of **implementation of equitable water and wastewater tariffs**	Degree of implementation of equitable and efficient water supply and wastewater tariffs	**3**	-	**3**	3	**2.5**	2
	-What share of population is using **improved sanitation services**?	Share of using improved sanitation services		3		3		3
En	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	**2**	1	**1**	1	**3**	3
	- What is the share of the **area equipped for irrigation that has become salinized**?	Percent of area equipped for irrigation that has become salinized		3		-		3

Table 6: Overview of resulting top-ranking options from the DST application and the M4W pilots in Egypt, Morocco and Tunisia

Egypt	Morocco	Tunisia
DST-based results		
EG1: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops **Technology suggested:** No treatment necessary **Costs:** No treatment	**MO1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops **Technology suggested:** No treatment necessary **Costs:** No treatment	**TU1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops **Technology suggested:** No treatment necessary **Costs:** No treatment
EG2: Reuse of typical municipal wastewater for agriculture purposes in desert areas **Technology suggested:** Lagooning: Australia I **Costs:** 0.39 USD/m^3	**MO2**: Reuse of typical municipal wastewater for irrigation of crops to be eaten raw **Technology suggested:** Wetlands: Nicaragua **Costs:** No treatment	**TU2**: Reuse of municipal WWTP typical secondary effluent for irrigation (NT 106.03 standard) **Technology suggested:** Wetlands: Nicaragua **Costs:** 0.15 0.39 USD/m^3
	MO3: Specific case of M'Zar Wastewater treatment plant with multiple reusers**.** **Technology suggested:** No treatment **Costs:** Distribution costs: 2.21 USD/m^3 (uphill elevation of 35m); 0.06 USD/m^3 (downhill elevation of 25m); 1.19 USD/m^3 (no elevation)	
Pilot-based result		
EG3: Reuse of drainage Canal Water for irrigation **Technology suggested:** M4W Pilot (Lake Manzala, Egypt) **Costs:** Flow of 1,000 m^3/d: 0.51 USD/m^3; flow of 10,000 m^3/d: 0.30 USD/m^3	**MO4:** Reuse of municipal WWTP tertiary effluent for olive trees irrigation **Technology suggested:** M4W Pilot (Agadir, Morocco) **Costs:** No treatment	**TU3:** Reuse of municipal WWTP secondary effluent for irrigation **Technology suggested:** M4W Pilot (Chotrana, Tunisia) **Costs:** Flow of 1,000 m^3/d: 1.25 USD/m^3; flow of 10,000 m^3/d: 0.59 USD/m^3
		TU4: Reuse of textile WW for non-food crops irrigation **Technology suggested:** M4W Pilot (Gwash, Tunisia) **Costs:** Flow of 1,000 m^3/d: 1.60 USD/m^3; flow of 10,000 m^3/d: 0.45 USD/m^3
Barriers and Measures		

Egypt	Morocco	Tunisia
Barriers: (i) Water is available too cheap; (ii) moderate share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW; (iii) lack of awareness and knowledge on wastewater reuse and further treatment facilities are required **Measures:** (i) Pricing/ water tariffs; (ii) remove subsidies or other financial assistance (e.g. assisted loans); (iii) taxes; (iii) capacity building; (iv) technology scale up	**Barriers:** (i) Water is available too cheap; (ii) lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW; (iii) lack of awareness and knowledge on wastewater reuse and further treatment facilities are required **Measures:** (i) Pricing/ water tariffs; (ii) remove subsidies or other financial assistance (e.g. assisted loans); (iii) taxes; (iv) capacity building	**Barriers:** (i) Water is available too cheap; (ii) lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW; (iii) lack of awareness and knowledge on wastewater reuse and further treatment facilities are required **Measures:** (i) Pricing/ water tariffs; (ii) remove subsidies or other financial assistance (e.g. assisted loans); (iii) taxes; (iv) capacity building; (v) lack of awareness and knowledge; (vi) legislation and enforcement on wastewater reuse

Figure 1: Water reuse for pre-feasibility in a systemic approach: (1) wastewater for reuse, (2) type of intended reuse, (3) identification and assessment of technology.

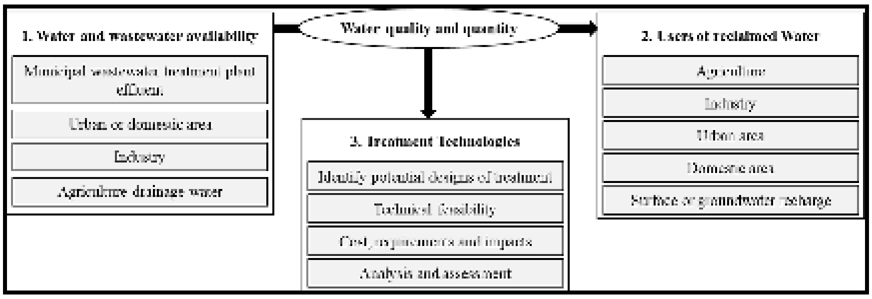

Figure 1: Water reuse for pre-feasibility in a systemic approach: (1) wastewater for reuse, (2) type of intended reuse, (3) identification and assessment of technology.

Figure 2: Application of the decision support tool (i.e. Poseidon)

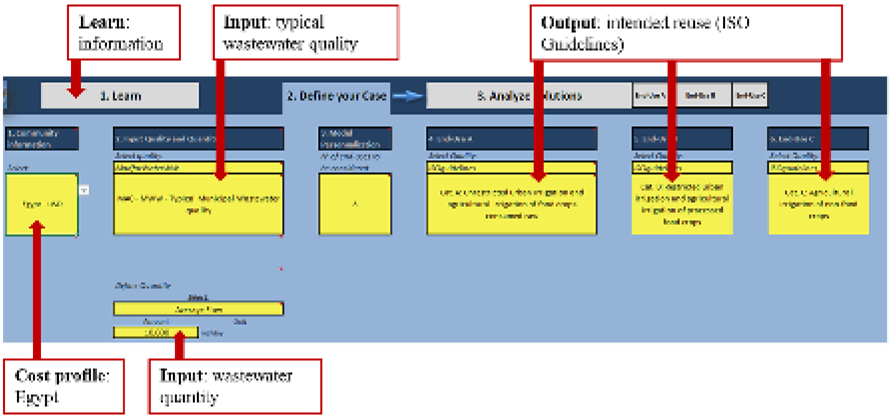

Figure 2: Application of the decision support tool (i.e. Poseidon)

Figure 3: Treatment trains lifecycle costs for different flow rates and countries.

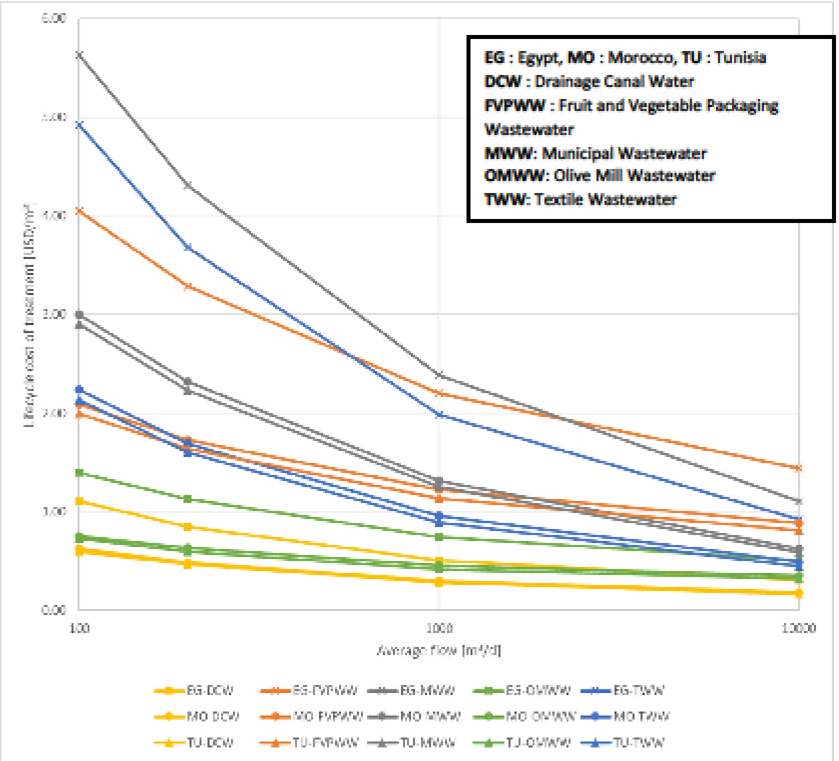

Figure 3: Treatment trains lifecycle costs for different flow rates and countries