Contract no. 688320

MADFORWATER

Development and application of integrated technological and management solutions FOR wastewater treatment and efficient reuse in agriculture tailored to the needs of Mediterranean African Countries

Deliverable No.	**D1.4**
Deliverable Full title	**Water vulnerability assessment framework**
Work Package No. and Title	**WP1 - Water and water-related vulnerabilities in Egypt, Morocco and Tunisia**
Lead beneficiary (extended name and acronym)	**WER**
Authors **(Acronyms of beneficiaries contributing to the deliverable)**	**Angel de Miguel, Judit Snethlage, Emma Daniels, Jochen Froebrich (WER)**
Planned delivery date	**15/11/2019 (M42)**
Actual delivery date	**10/01/2020 (M44)**
Dissemination level: **(PU = Public; PP = Restricted to other program participants; RE = Restricted to a group specified by the consortium; CO = Confidential, only for members of the consortium)**	**PU**
Project website	**www.madforwater.eu**
Project start date and duration	**Start date of project: 01 June 2016** **Duration: 48 months**

This project has received funds from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 688320

Table of Contents

List of figures

List of Tables

List of Abbreviations

AgrWU - agricultural water use

AWDO - Asian Water Development Outlook

C_t - total storage capacity

Cv,a - Inter annual variability

Cv,m - Intra annual variability

DDM - average hydrological drought duration

GDP_A - agricultural gross domestic product

IWLMS - Integrated Water and Land Management Strategies

PESTLE - Political, Economic, Social, Technical, Legal and Environmental analysis

S – score factor

SDL - drought-duration length

SLI - Storage Drought duration length index

SPI - Standardized Precipitation Index

SR - Storage ratio

SSA - Self-sufficiency in Agriculture

TRWR - total annual renewable freshwater resources

W_w - total annual freshwater withdrawal

W_m - monthly surface water withdrawals

WEI - Water Exploitation index

WPA - Water productivity in Agriculture

WS - Water Stress

WWTPs – wastewater treatment plant

WW – wastewater

1 Introduction

The present deliverable report is related to Task 1.4 of the MADFORWATER project, entitled: Detailed evaluation of water stress and water vulnerability for three selected basins in Egypt, Morocco and Tunisia, to explore strategies for non-conventional water use. The aim of the current report is double:

(1) To define a framework for the development and assessment of integrated water & land management strategies (IWLMS) at basin level. This will be subsequently implemented in WP5 and WP6 of the MADFORWATER project. This framework is mainly defined in section 2.

(2) To assess water security on a scale lower than the national level (as it was done in Task 1.2 of the MADFORWATER project) in order to provide a better understanding of the current water management practices and water vulnerabilities of the MADFORWATER selected basins: Souss-Massa basin in Morocco, Cap-Bon and Miliane basin in Tunisia, and the North-Eastern Nile Delta sub-basin in Egypt. The methodology and results of this assessment can be found in sections 3 and 4.

It became apparent, during the execution of the MADFORWATER project, the need to handle a stronger consistency of indicators and information across different scales. In this view, Deliverable 1.4 focused on a systematic analysis to understand how the impact of potential local measures in the field of wastewater reuse could be assessed at different scales. Results were then used to derivate the assessment framework accordingly.

Water Security and Water Vulnerability are political terms that reflect the perceived stability or risk to maintain a demanded livelihood. As outlined in Deliverable 1.2, they are related to the five key dimensions taken into consideration by the Asian Water Development Outlook approach (AWDO, 2016a): Human Water Security, Economic Water Security, Environmental Water Security, Urban Water Security and a principle capacity to handle risks.

Considering the political connotation of Water Security, it becomes clear that Water Security assessment frameworks, such as the AWDO 2016 (AWDO, 2016a), were predominantly applied at national scale. This is the scale where policy instruments are developed.

Interventions to improve or to deteriorate water security are however mostly applied at a local scale. This scale can be defined as intervention scale (see Fig. 1). In the field of wastewater reuse, activities at the intervention scale can comprise both measures to reclaim and reuse wastewater as well as to improve the economic crop water productivity (economic yield/m3). It is evident that, while individual measures can have a strong effect at local scale, their impact at a superordinate scale is nevertheless limited. Developing scenarios to predict the collective effect of measures at a higher scale remains difficult; measures are too much implementer-dependent. However, as depicted in Fig. 1, river basins are significantly influencing the agro-ecological context of water security, in which the measures take place and in which they become necessary.

At national scale, in most cases, different river basins must be considered. This is even the case when the basin territory stretches over more than one country, as in transboundary river basins. Therefore, the effect of a single intervention is even less visible at national scale. On the other hand, policy instruments to affect agricultural economics and to regulate water consumption are usually developed at national scale. Determining barriers and opportunities and shaping the enabling environment, the national scale influences hence largely the realisation of measures at the local intervention scale.

At regional scale, comprising multiple countries, the total water in-security can be actually larger (number of people at risk, total economic damage, and total environmental degradation) but effective policymaking remains usually at national scale. Nevertheless, a consideration at regional scale is helpful to improve the awareness raising at national scale.

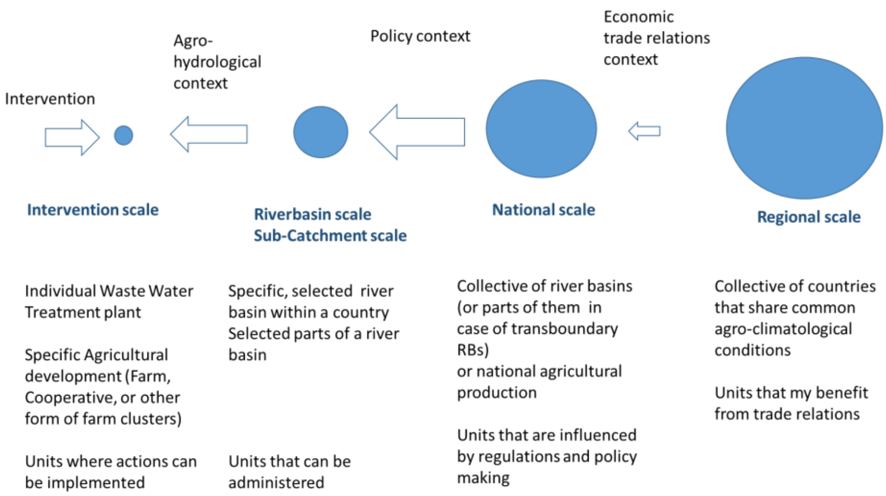

Figure 1: Water Security/ Vulnerability at different scales in its total dimension (blue dots), the related interrelations to be considered and the influence of different scales on local measures.

Overall, the work for Deliverable 1.4 made clear that to assess water security and to derive applicable measures, one must consider the various scales differently. For doing that, usually the adaptation of the approach is required, since not all the indicators used at national level have a significant meaning at lower scales.

While the river basins in Tunisia and Morocco are characterized by a natural dynamic of rainfall, runoff and by an anthropogenic abstraction, the situation in Egypt must be regarded in a completely different way. All water within the Nile Valley and its Delta originates from the Aswan High Dam and a differentiation of available natural water resources in the different sub-regions will not deliver sensible additional information. Instead, the case of Egypt offered valuable insights to elaborate detailed water balances at local intervention scale. This helped to understand the overall potential contribution that municipal wastewater reuse can bring to improve water security.

In this view, Deliverable 1.4 synthesized first a comprehensive framework to consider the different scales within the water vulnerability assessment tool.

In the subsequent part, water vulnerability and water security are analysed for each of the selected basins based on the current situation, and the calculated situation is compared with the water security score obtained at national level in Deliverable 1.2

Overall, this analysis represents the basis for the development in WP5 and WP6 of Integrated Water and Land Management Strategies (IWLMS) effective in the overcoming of the identified water vulnerabilities.

2 Current Water Stress and Water Security framework

2.1 Principle considerations for improving water security by wastewater reuse

Developing a framework that allows the assessment of IWLMS for improving water security or reducing water vulnerabilities will benefit from an in depth understanding to which extent wastewater reuse in agriculture is affecting the water balance.

All river and groundwater resources originate from rainfall within a river basin (as long seawater desalination is a not applied). This is also referred to as blue water.

All water that is used in agriculture is actually consumed by evapotranspiration during crop growth and cannot be reused within the river basin. This is also referred to as green water.

Within a river basin, two basic types of wastewater reuse can be differentiated. Indirect reuse of wastewater occurs as the abstraction of river water takes place downstream of a discharge of wastewater into a stream. A direct reuse occurs, if the wastewater is directly brought to the agriculture lands, without entering temporarily into the river. It becomes obvious that shifting from indirect use to direct use will not lead to any gain of water resources for agricultural production. In case of maintaining the indirect re-use, the stream flow downstream is reduced accordingly.

A well-planned direct re-use will limit the discharge of pollutants into the river, reducing the water risk related with quality at the same time that the reuse of nutrients could limit the dependency on mineral fertilisers. In other words, any increase of agricultural water consumption at upstream areas will lead to a reduction of remaining freshwater resources downstream accordingly.

Benefits (from a river basin perspective) for using wastewater in agriculture to improve water security can be expected under the following conditions:

- Proper treatment and reuse of reclaimed water will improve the water quality in river sections, minimizing water risk related with water quality. If water reuse is well planned, this effluent should substitute the abstraction of fresh water from the river, keeping the water flowing on the river less impacted by untreated discharges. A usual practice in many semi-arid areas of the world is to discharge more or less treated wastewater from municipalities into the riverbeds. In particular during the hot summer months there is little or often no dilution at all, resulting into severe environmental degradations for the aquatic fauna, that otherwise had been adapted to survive in pools or the interstitial waters below rocks. The flushing of riverbeds with the onset of the rain period leads then to a disproportional high load of nutrients to the downstream section.

- More predictable water availability. Switching from indirect re-use to direct re-use may increase the predictability that water resources are readily available. Discharges in rivers at low flow conditions may vary and can be affected by uncontrolled abstractions in between. Furthermore, as better defined the source of water is (e.g. from large food processing industries), as easier it gets to identify the exact pollution and to optimize the treatment and monitoring accordingly. In such cases, and in comparison to a sourcing of water from a river, water quality becomes also more predictable. A higher predictable availability of water can justify in some cases the investment into advanced irrigation technologies and to strive for crops of higher economic value.
- Direct reuse of treated wastewater will limit the health risk of using uncontrolled sources of water. At is was pointed out in the first conditions, most of the farmers from semi-arid countries abstract fresh water of questionable quality. Since the water is coming from a natural source, there is usually a lack of regulation controlling the minimum quality to be used. On the contrary, most of the countries have already established some regulations to control the direct water reuse, forcing in most of the cases, at least to a set of treatments to minimize the health risk on users and consumers.
- Targeting downstream sources of wastewater close to the outlet to the sea. There are many examples worldwide where towns such as Rabat, Tunis, and many more are located at coastal areas. Municipal wastewater is often discharged to the sea. Reusing such wastewater may offer opportunities to increase the agricultural production without affecting the stream flow upstream. However, the economic feasibility depends on how close to the treatment plant an agricultural production can be realized. As longer the distance and as higher the elevation is, as faster, the costs for pumping the water back to agricultural areas, can prevent an economic viability of the measure. Reducing clean freshwater flow to the sea can affect the local marine environment significantly. Discharging less treated municipal wastewater to the sea can lead to damages from pollution too. It is a matter of political decision making to decide the level of damage that is acceptable and to weigh the advantage reducing the pollution.

In summary, interventions for reusing wastewater are of limited effect to improve the water security at the scale of a river basin. However, they can be of strong local impact to improve the reliability of local water supply, to stimulate technological developments, and to reduce the discharge of pollutants to rivers and the sea.

In this view a combination is required that improves the situation awareness for water vulnerability at all related superordinate scales, as well as allowing the detailed consideration of local conditions and the prediction of possible impacts at local sale.

2.2 Approach for Characterising Water Stress and Water Security

The approach to characterize water security in view of forthcoming local interventions must consider the multiple scales that are dealt with. At the same time, it is important to note that the approach focuses on the determination of the current situation (baseline) and the context in which the measures will be initiated.

Furthermore, there are different domains to be considered, such as hydrological circumstances, agronomical aspects, and technological and economical features in treating and reusing wastewater.

The more you zoom into the scale, the more relevant it is to identify and to apply the appropriate specific indicators that characterize a particular intervention, the related requirements to realize it and to determine the related possible impact. The comparison to other interventions at distant locations becomes less relevant, while a sound identification of specific bottlenecks and relevant impacts are getting critical.

With an increasing geographical scale, the comparability between locations and over different times of investigation becomes more and more relevant. In such a case, the consistency of indicators is essential.

Overall, there is a need to provide a nested framework that allows the assessment of multiple scales and different indicator sets.

The proposed approach, illustrated in Figure 2, differentiates the initial characterization of the water security baseline both at national and at basin scale (left part), a specific multi criteria assessment for planning the concrete measures at local intervention scale (middle part) and the rechecking of barriers and opportunities at national scale (right part). This framework has to be understood as an integration of several tasks developed within the project in different work packages (WPs 1, 5 & 6) and different partners into a streamlined and harmonized structure.

A further description of the several components of the integrated assessment framework proposed can be found in the following sections (from 2.2.1 to 2.2.4).

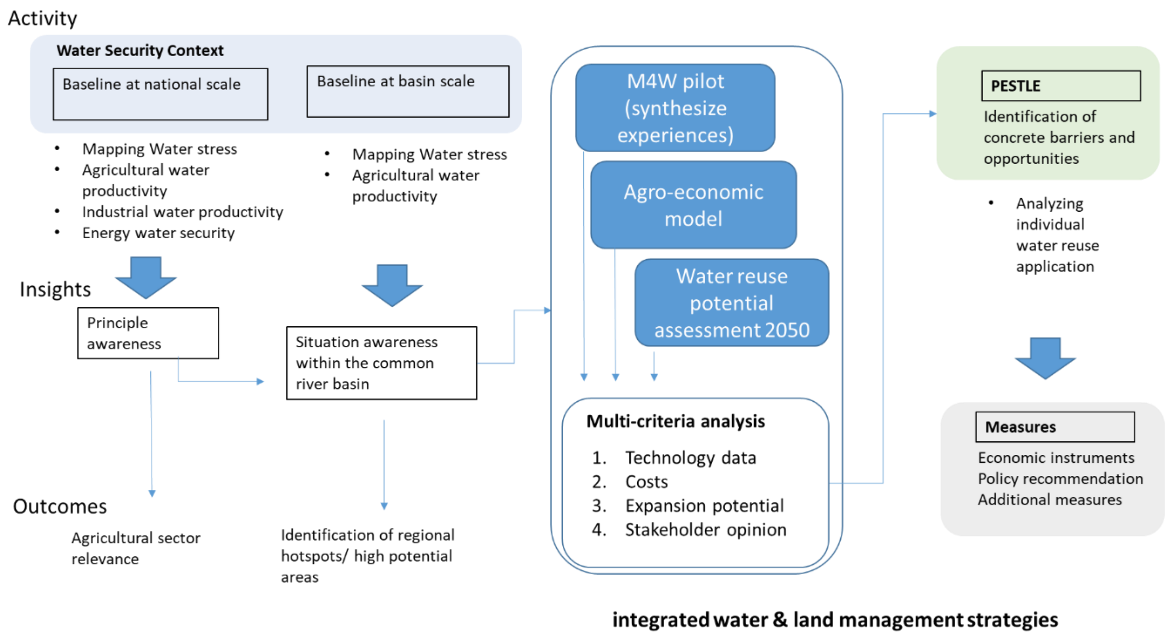

Figure 2: Components for an integrated assessment framework that considers the multiple scales of relevance when linking local measures to a regional characterization of water vulnerability/ water security

2.2.1 Characterization of Water Security at national scale

The Asian Development Bank (ADB) and the Asia-Pacific Water Forum (APWF) developed in 2016 the latest version of the Asian Water Development Outlook approach (AWDO, 2016a). The ADB developed the approach to provide a periodically quantitative and comprehensive review of water security in the countries of Asia and the Pacific. This water security framework provides a comprehensive national overview for five Key Dimensions related with household, economic, urban, environmental, and resilience to water-related disasters.

The assessment of the water security at national scale developed in Task 1.2 makes use of the AWDO2016 (AWDO, 2016a) approach and focus on the Key dimension 2 – Economic Water Security. Applying this dimension offers a sufficient comparability to the situation at other countries in the region. Moreover it can be used later to balance the relevance of agricultural water security to other dimensions (e.g. environmental water security), if desired and compared with the evaluations reported for other countries, as it was successfully applied by other authors in the South of Africa (Holmatov et al., 2017). Therefore, this Key Dimension provides by itself valuable information for policy makers.

Specifically, the evaluation of the economic water security comprises a standardized assessment of the natural water resources availability, their temporal variability, and the ratio of water resources availability and its consumption. Analysing the agricultural water productivity, the industrial water productivity and the energy water security in a consistent way, allows placing the agricultural water challenges in a broader view. A detailed description for the approach chosen is provided in the Deliverable 1.2 of MADFORWATER.

Because of the national water security assessment, one may gain a principle awareness on the agriculture- related water vulnerability within one country. This helps to understand the relevance of the agricultural sector when aiming to improve the water security at national scale. Results should be used to derive specific political and financial instruments. These instruments can stimulate an increase in both the GDP and economic water productivity, while reducing the total consumption of water resources at the same time.

2.2.2 Characterization of Water Security at basin scale

To analyse spatial variations of water security within a country, it is proposed to elaborate a consistent subset of indicators from the Economic Water productivity on the scale of a river basin.

If the selected country comprises of multiple river basins, such an analysis can provide an appropriate perception of how the situation differs in the various river basins. Moreover, it provides insight where future interventions should be spatially prioritized.

If the river basins are covering a territory that is larger than one country (such as in the case of the river Nile, the Danube etc.) an analysis of the entire basin with its sub catchments is recommended. This is done to gain further insights from comparing the situation amongst the riparian countries.

At the scale of a selected river basin and if it is located within one country, calculating the energy water security can be omitted if the electric energy is distributed in a national wide power grid.

Agricultural water consumption often exceeds the industrial consumption with a big amount. In this case, the effort to obtain the data for calculating the industrial water productivity cannot be justified. If the analysis at national scale instead provides some indication that the industrial water security might be of significant relevance under the given circumstances, the related indicators should be investigated accordingly.

In all other cases, mapping the water stress and the agricultural water productivity provide a good opportunity to compare the specific situation at a particular river basin with the statistical country average.

Overall, this will increase the awareness on the relevance of initiating measures for a particular river basin.

2.2.3 Specific Multi-Criteria Analyses

Each intervention is unique and characterized by specific technologies used and combined. Likewise, each setting in which the intervention will be realized, differs in terms of costs and regulations.

The initiation of interventions requires a detailed investigation of the local circumstances. Moreover it provides the base line for the follow up planning.

A first investigation of possible high potential areas can help to define relevant sources for reclaimed water as well as to identify suitable agricultural areas. Results can be used on the one hand to identify new, best-suited specific locations for the future interventions. On the other hand, if a location was already chosen for other reasons, the identification of high potential areas can be used to compare the suitability of this location.

Using the experience of the MADFORWATER project, the development of a Pilot phase before the final implementation is highly recommended. Next to insights of the technical details, such pilots facilitate above all to familiarize with the given regulations, permissions required, associated costs from energy supply and operations. Pilots can reveal important experiences into maintenance intervals and other experiences that need to be considered in a full scale.

Applying agro-economic modelling, such as done in the MADFORWATER project, can help to identify relevant market related information for the targeted agricultural production. Insights can be used to identify possible return of investments and related financial risks that originate from market volatilities.

Results from the above-mentioned modules must be supplemented with individual technical background information, in particular if they had not been collected within the pilot phase.

Within the next step, all information gathered should pass multi criteria analysis to identify a) technological suitability b) costs and revenues, c) its expansion potential, and d) the ranking of stakeholder opinions. The results deliver again further detailed insights, which combination of technologies and agricultural water uses might provide the most promising set ups under the given local specific circumstances.

2.2.4 Rechecking barriers and opportunities

As it showed in Figure 2, in a final assessment step, a PESTLE analysis (P for Political, E for Economic, S for Social, T for Technological, L for Legal and E for Environmental) aims to identify the main drivers and barriers related with the political, environmental, social, technical, legal and economic aspects towards the regional implementation of the MADFOWATER strategies (measures). The Drivers & Barriers analysis is mainly based on the assessment made by the regional stakeholders during the different stakeholders' consultation workshops.

The PESTLE can be used to recheck for the potential wastewater reuse applications identified, the prevailing political, environmental, social, technical, legal and economic conditions. Results will help to facilitate a successful implementation. Moreover, the results will help to finally select concrete wastewater reuse interventions as part of an IWLMS to improve the water security. Results can be used to derive economic instruments, policy recommendations and any additional measures to support the implementation accordingly.

3 Assessing water security at basin level

3.1 The 2016 AWDO assessment framework

The 2016 AWDO assessment framework (AWDO, 2016a) is one of the very few frameworks that has not only received the support from relevant international organisations such as the Global Water Partnership (GWP), Asian Development Bank (ADB), Food and Agriculture Organization (FAO) and the International Water Management Institute (IWMI), but that also has been applied in a recurrent way in 2007, 2013, 2016 and 2020 (upcoming release) for all countries in the Asian Pacific region.

Utilizing the modular concept of the 2016 AWDO approach allows the restriction on a single Key dimension. The Key dimension 2 (Economic Water Security) has been chosen for this study, as it offers a systematic Water Stress characterization and provides the most relevant linkage to a potential wastewater ruse. Within the Key dimension 2, Economic Water Security, the characterization of Water Stress is an intrinsic and explicit part of the assessment. Given the related and inverse nature of Water Security and Water Vulnerability, a characterisation of Water Vulnerability is included implicitly.

As mentioned in the previous section, in the framework of MADFORWATER, a water security assessment is developed at two different scales. At national scale, in order to get a general overview about the water related issues for the three countries under study (Morocco, Tunisia and Egypt). In addition, at river basin level, in order to reflect better the requirements of the project and provide the basis for a further analysis of the potential alleviation effects of local wastewater reuse interventions on water security.

The national assessment, including the most prominent results and maps for characterising water security, was previously presented in the public report "Deliverable 1.2 Water stress and Water Vulnerability indicators and maps". Therefore, the water security assessment developed in the current report focuses on the 3 selected basins: Souss-Massa basin in Morocco, Cap-Bon and Miliane basin in Tunisia, and the North-Eastern Nile Delta sub-basin in Egypt. A comparison of the results between the water security at national level and the water security for the selected basins can also be found.

Due to the hydrological particularities of the North-Eastern Nile Delta sub-basin, which mainly depends on the water derived from the Nile River and not on the natural water available, it is not possible to apply the AWDO approach to a scale lower than the national level, as it was done for the other two river basins. In this particular case, the water security is assessed by performing a water balance for the North-Eastern Nile Delta sub-basin and comparing the results with the national figures.

3.2 Methodology

The characterization of the Economic Water Security as presented in this study follows a nested approach using selected indicators from the 2016 AWDO assessment framework. It combines both the elaboration of spatial explicit Water Stress related indicators with indicators developed at basin or regional level. In both cases, the subsequent aggregation of information for describing the Economic Water Security at basin scale was required.

A detailed description of the methodology, including the scoring tables per sub-indicators, can be found in the AWDO report (2016b) and in the previous report "Deliverable 1.2 Water stress and Water Vulnerability indicators and maps" of MADFORWATER. However, a short description of the general AWDO approach as well as the particularities of the methodology used to develop the Economic Water Security assessment at basin level can be found below.

The 2016 AWDO key dimension Economic Water security is based on the performance of four indexes (Figure 3), a general one to assess the water-related boundary conditions (Water Resources Index) and three sector-specific indexes (Agriculture, Energy and Industry Indexes). Each of these four indexes is composed by different levels of sub indicators. The value of each sub indicator is transformed into AWDO scores, ranging from 1 to 5, by using the scoring tables (AWDO, 2016b). The final total score of each sub indicator is subsequently aggregated into the final Economic Water Security dimension to a maximum of 20 points, according to the weight established in the methodology (see score values in Figure 3 and Table 1).

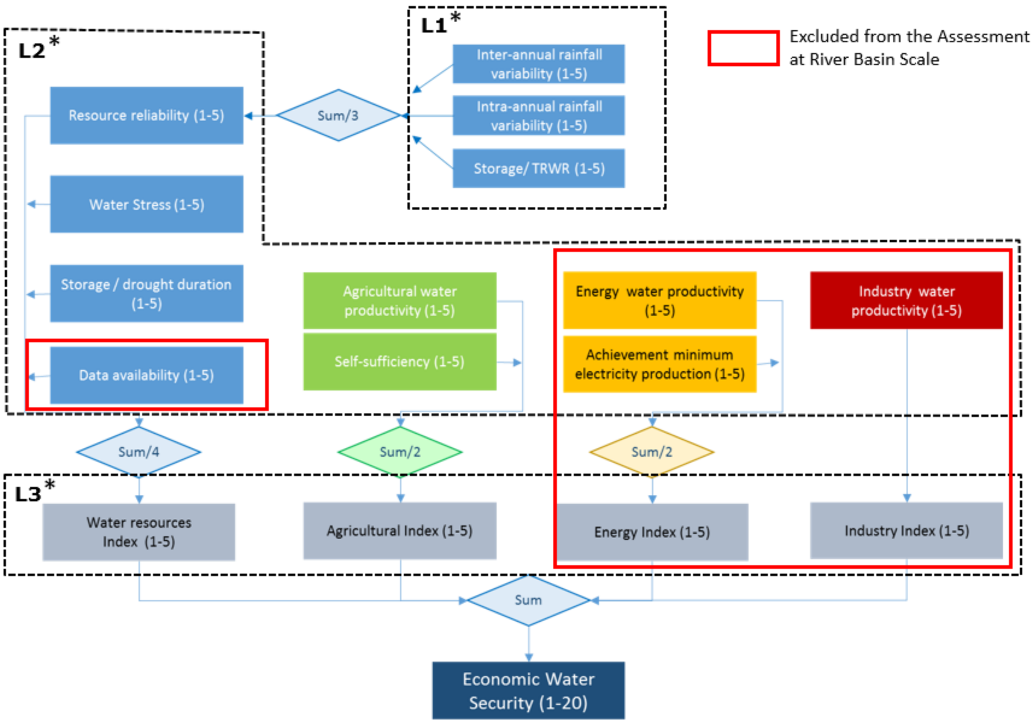

Figure 3: Structure of the 2016 AWDO Key dimension II- Economic Water Security.

**L1, L2 and L3 refers to the three levels of sub-indicators of the AWDO methodology*

For the economic water security assessment developed at basin level, an adjusted AWDO approach has been used, restricted to the indicators comprehend to Water Resources Index and Agricultural Index. In this way, the weight of each sub-indicator (L3) has been modified proportionally to a maximum value of 10. This is because: i) in case of the Industry Index, no reliable information was found at basin level; ii) in case of the Energy Index, since the electricity network is interconnected at national level, not make any sense to differentiate the source of the energy on scales lower than the country.

The Water resources Index of the AWDO approach includes a sub indicator called Data Availability, to assess how data availability could obstruct the assessment and monitoring of the water security of a region and interfere the decision-making process. This sub indicator evaluated the accessibility to a total of eight key data required for the calculation of the required sub indicators. However, this information is not available at basin scale, so the sub indicator was removed from the current assessment and the weight of each sub-indicator (L2) has been modified proportionally.

A description of the different sub indicators and the weighting factor over the 10 points score for the adjusted Key Dimension Economic Water Security could be found in

Table 1. As well, a short description of the methodology used and data sources can be found in the following sections.

Table 1. Sub indicators of the key dimension Economic Water Security of the adapted AWDO approach applied at basin scale.

Sub Index	Symbol	Total Weight*	Max. score**	Level	Description
1. Broad Economy Index (water resources)	-	1/2	5	L3	Describing the general water-related boundary conditions for the use of water for economic purposes
1.1 Resources reliability		1/6	1.6	L2	Indicating the resilience to water availability fluctuations
1.1.1 Inter annual variability	Cv,a	1/18	0.55	L1	Rainfall coefficient of variation between years
1.1.2 Intra annual variability	Cv,m	1/18	0.55	L1	Rainfall coefficient of variation within the year
1.1.3 Storage ratio	SR	1/18	0.55	L1	Relation between storage capacity and the total renewable resources
1.2 Water Stress	WS	1/6	1.6	L2	Relation between freshwater withdrawal and total renewable resources
1.3 Storage Drought duration length index	SLI	1/6	1.6	L2	Indicating the duration that the economic sectors could be supplied by

					the water stored in dams during a dry period
2. Agricultural Index	-	1/2	5	L3	Indicating water productivity in agriculture and food security
2.1 Water productivity in Agriculture	WPA	1/4	2.5	L2	Relation between the gross domestic value of agriculture and the water used by the sector
2.2 Self-sufficiency in Agriculture	SSA	1/4	2.5	L2	Relation between the annual water footprint of agricultural goods consumption divided by the annual water footprint of agricultural goods production (net balance of imported virtual water).
Economic Water Security		1	10		

*Total weight over the 10 point score of the Key Dimension Economic Water Security
**Maximum score that could be reached per subindicator over the 10 point score of the Key Dimension Economic Water Security

3.2.1 Sub-Indicator – Broad economy Index (Water resources index)

The Water Resources Index is a compound out of the sub-indices Resource reliability (Cv,a, Cv,m and SR), Water Stress (WS), and Storage Drought Duration Length Index (SLI). Each sub-index was calculated on an spatial explicit way and subsequently aggregated to a basin scale.

3.2.1.1 Resources reliability indicators

According to the AWDO approach (2016a), the resources reliability indicators are those used to measure the degree to which areas have achieved assurance of stable supply across sectors, so that à region's economic activities are more assured when there is enough storage to assure reliable and timely supply and to mitigate risk.

In the current assessment, an special-explicit assessment was developed for the calculation of the inter, intra-annual and storage ratio for all the North African Countries. Subsequently, grid information was extracted and summarised at basin level. The hydrological catchments are extracted as vector data from the Global Drainage Basin Database (GDDB) (Masutomi et.al, 2009). In all cases, data were processed with the software R (R-core, 2013).

3.2.1.1.1 Inter-annual rainfall variability

The Inter-annual variability (Cv,a) is calculated by the coefficient of variation from long-term time series on mean annual precipitation.

$$Cv,a = \sigma_{\text{mean annual precipitation}} / \mu$$

Where Cv,a is the coefficient of variation; σ is standard deviation and μ is the mean annual precipitation (mm) over the period to be considered.

Monthly and yearly rainfall data are extracted from Climate Hazards Group InfraRed Precipitation with Station data CHIRPSv2.0 (Funk et al., 2015) on a 0.05-degree resolution for the years 1981 up to date (2017). This information was used to estimate the current Inter and Intra-annual rainfall variability. CHIRPS is a quasi-global rainfall dataset with more than 30 years of data. It incorporates satellite images with stations on the ground to create gridded rainfall time series (Funk et al.,2015).

3.2.1.1.2 Intra-annual rainfall variability

The intra-annual variability (Cv,m) is calculated by determining the variability between long-term average monthly precipitation data. The same data source and method is used as for analysing the inter-annual rainfall. The major difference is that the intra-annual rainfall, the variation within the year is collected and not between the years.

$$Cv,m = \sigma_{\text{monthly precipitation}} / \mu \qquad \sigma_{\text{monthly precipitation}} = \sqrt{\frac{\sum_{i=1}^{12} (P_i - \mu)^2}{\mu}}$$

Where Cv,m is the coefficient of variation; σ is standard deviation and μ is the monthly precipitation (mm).

3.2.1.1.3 Storage ratio - Storage capacity related to the Total Renewable Water Resources

In the case of both a high inter-annual variability as well as a high intra-annual variability of rainfall, a sufficient storage capacity contributes to a higher Water Security for economic uses. “A higher ratio of storage to total renewable water resources indicates that a country is more resilient to changes. Conversely, a higher rainfall coefficient of variation and lower ratio of storage to total renewable water resources indicate that a country is less prepared for water fluctuations (AWDO 2016)”

The storage ratio related to the total renewable water resources, SR is calculated as

$$SR = C_t / TRWR$$

Where C_t is the total storage capacity within a region of consideration (km^3) and TRWR is the total annual renewable freshwater resources within a region of consideration (km^3).

Location and volume of major dams (bigger than 20 Mm^3) is extracted from the Geo-referenced database of Aquastat (FAO Aquastat, 2016). The location of some missing dams in the database was updated by using Google Earth. Due to the dynamic development and the building of new dams, even statistics at country level may differ significantly from source to source.

The Total Renewable Water Resources (TRWR)[1] provides an estimate of the maximum theoretical amount of water resources in a country (FAO Aquastat, 2016) and comprises the average annual natural inflow and runoff that feed each hydro system (catchment area or aquifer). It consists of the internal renewable water resources (km^3/year) and the external renewable water resources, flowing from outside into the unit of consideration.

Data from the AQUEDUCT database (Gassert et al., 2014) is used to derive TRWR at basin level. For this, the total blue water, defined as natural river discharge at the outlet point of a basin, is considered.

3.2.1.2 Water Exploitation Index

Within the 2016 AWDO framework, the total Water Stress on freshwater, is defined as the total amount of water abstracted from freshwater sources for human use related to the TRWR. This ratio also known as Water Exploitation index and in the further reporting referred to as WEI.

$$WEI = W_w / TRWR \ (-)$$

Where W_w is the total annual freshwater withdrawal (km^3) and TRWR is total annual renewable freshwater resources within a region of consideration (km^3).

While a high Water Stress implies risks in the Water Security, a lower fraction of abstracted water resources reflects greater Water Security for economic growth and production.

Although data at river basins scale is available worldwide at the World Resources Institute WRI database (Gassert et al., 2014), in order to get a more precise information, data from the annual report of the COMMISSARIAT REGIONAL AU DEVELOPPEMENT AGRICOLE NABEUL (CRDAN, 2016) was used for Tunisia and from the Plan Blue (El Badraoui and Berdai, 2011) for Morocco.

3.2.1.3 Storage – Drought (Duration) length index

The drought duration is calculated to give the average length (in months) of a drought that was moderate, severely and/or extremely dry in intensity as given by the Standardized Precipitation Index (SPI) (Svoboda et al., 2012). The Standardized Precipitation Index (SPI) is a widely used index to characterize temporal aspects of meteorological droughts. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean, as is calculated as:

$$SPI = (P-P^*) / \sigma P$$

[1] UNESCO IHP refers to Total Actual Renewable Water Resources- TARWR

Where P is the precipitation during a certain period (mm), P* is the average precipitation for a long term period (mm) and σP is the standard deviation of P.

The occurrence of a drought event is referred to any time, where the SPI is continuously negative and reaches an intensity of -1.0 or less. First, for every month, the 1-month SPI was calculated. Next, the number and duration of droughts, when SPI was equal to or smaller than 1, was recorded. Finally, the duration of droughts was averaged.

As for the inter and intra-annual variability, the drought duration is spatial-explicit calculated from the rainfall information from the database CHIRPS v2.0 on a 0.05 degree resolution for the years 1981 up to date (2017).

The AWDO framework adopted the storage drought-duration length (SDL) index from (Eriyagama et al., 2009). This index expresses the capacity to cope with droughts. "A higher proportion of months with reliable water supply indicates greater Water Security for economic activities." (AWDO, 2016a). It first determines the duration how long the storage capacity in a country (Ct) is sufficient to supply average monthly surface water withdrawals (W_m). This duration is then related to the average drought duration in months.

The Storage-Drought duration length index SDL is calculated as

$$SDL = (Ct/ W_m)/ DDM \ (-)$$

Where Ct is the Storage capacity in a country (km^3); W_m is the average monthly withdrawal (km^3/ month) and DDM is the average hydrological drought duration (months).

This index can be understood as extending a merely meteorological consideration of droughts with relevant managerial aspects. Concerning the storage capacity, the same remarks on actual available capacities, as stated above, does apply are here as well. The other challenge in considering the storage capacities to cope with droughts is that the Water Security depend to a large extend from the filling status of the storages. Especially in periods of consecutive dry spells and repeating droughts, the water available in the dams is at minimum and far from the reported minimum.

3.2.2 Sub-indicator - Agricultural Index

The enormous relevance of water to secure the food production within a country is widely understood in science and policymaking. Agriculture was a longer time not high on the agenda, but both the milestone report Water for Food – Water for life as result of the comprehensive assessment of water in agriculture and a series of food crisis underpinned the utmost importance of agricultural water management. Agriculture is not only a strong backbone and a nucleus to advance national economies, but especially in rural areas, a vitally factor to maintain employment and a quality of life.

Within the Sub-Indicator Agricultural Index, the 2016 AWDO framework considers two dimensions. Firstly, the Agricultural Water productivity WPA, as the degree to which extend there is a readiness of the sector to use the scarce resource in an efficient way. Secondly, the Self-sufficiency in Agriculture, depicting the resilience of the agricultural sector against shocks and temporary production shortfalls. Within this study, the calculation of the Self-sufficiency in Agriculture is omitted as the underlying assumption is somehow incomprehensible. More evidence should be gathered that a higher self-sufficiency indeed would reduce the resilience against water scarcity.

3.2.2.1 Water productivity in Agriculture

AWDO 2016 determines Agricultural Water Productivity by associating the agricultural gross domestic product to water consumption for the agricultural production.

The water productivity in the agriculture sector is calculated as:

$$WPA = GDP_A / AgrWU \ (\$ \text{ million}/ \text{ km}^3)$$

Where GDP_A is the agricultural gross domestic product (million \$) and AgrWU is the agricultural water use (km^3).

According to the AWDO 2016, higher agricultural water productivity indicates a higher Water Security. Increasing the agricultural water productivity coincides with either increasing the production, which reflect skills in farming and/ or in skills to reduce the unproductive losses.

Data on the Agricultural Gross domestic product AGDP are partly available at regional level for the mentioned countries, so a proxy to extrapolate regional information to a basin level was used. In case of Morocco, a combination between the agricultural production (tons) for the regions located in the Souss Massa basin for the main crops (MAFRDF, 2017) and the Agriculture Producer Prices ($/tons) at national level (FAO, 2019) is used. In case of Tunisia, information of Agricultural Productivity collected in MADFORWATER (Deliverable 3.4 - water & crop allocation model) and the total water used by the agricultural sector in the basin from the report "commissariat regional au developpement agricole nabeul" (CRDAN, 2016) is used.

3.2.2.2 Self-sufficiency in Agriculture

For calculating the Self-sufficiency in agriculture the ratio between the water footprint of agricultural goods consumptions and agricultural goods productions is used. This was done in order to determine the dependency of an area from the external water footprint. Values from

Schyns and Hoekstra (2014) at basin level were used for Morocco. In case of Tunisia, information from Chouchane et al., (2015) for the North of Tunisia was used.

3.2.3 Water balance for the North-Eastern Nile Delta sub-basin (Egypt)

As mentioned before, due to the hydrological particularities of the North-Eastern Nile Delta sub-basin, it is not possible to apply the AWDO approach to a scale lower than the national level. This is because water availability on the various irrigation districts of Egypt (there is no real hydrological sub-basins in Egypt) depends on the water derived from the Nile River and not on the natural water available. In Egypt, around 96% of the TRWR is contributed by the flow of the Nile River. Moreover, it is regulated by the Aswan reservoir according to the Nile Waters Agreement of 1959 between Egypt and Sudan. The water, established in 55, 5 km^3 for the whole country, is regulated by the Aswan reservoir located upstream and subsequently distributed to the different irrigation districts.

Most of the sub indicators for the Broad economy Index from the AWDO approach are related with the natural water availability (i.e. Resource reliability, Water Stress or Storage Drought Duration Length Index) but the water available in the North-Eastern Nile Delta sub-basin only depends on the water derived by the Aswan reservoir. That means water security at local or regional scale in Egypt is more dependent on the agreements taken by the water managers on how much water is derived, when and to whom, than the environmental or infrastructure constrains.

To get some insights about the water security in this region, the water security is assessed by performing a water balance for the North-Eastern Nile Delta sub-basin and comparing the results with the national figures. The main source of information for the national water balance is derived from the document "Support to the National Water Resources Plan for Egypt, Water security for all" (MWRIARE, 2005).

The area selected for the North-Eastern Nile Delta sub-basin is the Bahr Baqr drain. The drain is a typical example for drains in Egypt. The Bahr Baqr drain is the main canal for wastewater disposal in the distinct area between Cairo and the Northeastern area of the Nile delta (Stahl et al, 2009). It drains directly to Lake Manazala. The lake is directly connected to the sea and it is used for fish production.

To see if wastewater reuse in the Bahr-Baqr drain can contribute to water security, the following points are researched:

- How much outflow there is to the sea (possible water profit)
- How much wastewater from towns/industries is flowing into the drain
- How much of the wastewater is coming from the municipalities in the drain

The national water balance was extracted from the before mentioned document "Water security for all" (MWRIARE, 2005). The main elements of this national water balance are:

- Net supply. Total amount flowing into the system.
- Net consumptive use. Amount of water used for crop growth, human consumption and for industrial consumption.
- Reuse. Proportion return flow that is captured to pass through the system again.
- Net outflow. Proportion return flow, which is not recovered by reuse

The selection of the water balance elements for the Bahr Baqr drain are based on expert opinions with more than 30 years of experience in Egypt (Koen Roest, Robert Smit and Wouter Wolters from WUR). The calculations for the drain are based on the SIWARE model. The SIWARE (Simulation of Water management in the Arab Republic of Egypt) model was first developed in the 1980s (Rijtema et al, 1994; Roest et al, 1994; Abdel Gawad et al, 1991 and 1994; Sijtsma et al, 1995; DRI/SC-DLO, 1995) and used several times by Egyptian institutions to support decisions from the Ministry of Water Resources and Irrigation. SIWARE is used for the Bahr Baqr water balance for the following posts: Agricultural drainage, municipal and industrial return flows, seepage. The model is also used to estimate amounts of the EB13 station and the outfall of the Bahr Baqr drain (outflow to Lake Manazala). To develop the water balance at Bahr Baqr drain, the elements reported in Table 2 were considered.

Table 2. Elements considered in the water balance for the Bahr Baqr drain.

IN	**OUT**
Gabal Asfar (wastewater treatment plant)	EB13
Agricultural drainage	Open water evaporation (1% discharge)
Municipal& Industrial return flows	(Potential) Armed forces
Seepage	Outfall Bahr Baqr drain

4 Results

4.1 Characterising Water Stress and Water Security in the Souss-Massa basin

4.1.1 Results: Souss-Massa basin

According to the Plan Blueu (El Badraoui and Berdai, 2011), the Souss-Massa basin presents a TRWR of around 901 Mm^3/year (476 Mm^3/year surface water and 425 Mm^3/year groundwater), while the water demand is estimated in 1068 Mm^3/year. That means there is a complete unbalance towards the water demand. Within this demand, agriculture is the highest consumer, with around 994 Mm^3/year (93%). The total irrigated area is estimated in 148,000 ha/year. This figure corresponds to around 9% of the total irrigated area of the country.

From the Economic Water Security assessment developed, we can state that the Souss-Massa basin gets a score of 4.9 over 10 (*Table 3*). This value is far much lower than the 6.9 score calculated for the whole Morocco (Figure 4). This figure indicates that water security in this region is lower than the national average value, where the score is also not very high.

Both the Broad Economy Index and the Agricultural Index provide a similar aggregated value to the final score, with around 2.5 points over 5 for each Index.

As shown in Figure 4, the sub-indicators with the highest impact over the total score are SLI (belonging to the Broad Economy Index) and WAP (belonging to the Agricultural Index). This is very similar to the results obtained for the whole country. However, both SLI and WAP are smaller than the final score estimated at national level (Figure 5).

The score of SLI is mainly related with the large capacity of the basin to store surface water, estimated in around 800 Mm^3. As the sub-indicator SR indicates, the reservoir capacity of the basins is almost 100% of the TRWR. This large reservoir capacity allows the basin to surplus the required water during at least 10 months without precipitation, giving a certain resilience to the water dependant sectors.

WAP is also of great importance, indicating that the economic return from the water used in agriculture is remarkable, with values estimated in around 521 Million USD/Km^3.

Table 3. Final values calculated and Economic Water Security score, Souss-Massa basin (Morocco*)*

No.	Index descriptor	2016 AWDO Scoring			
		Score	L1*	Aggregated L2*	Aggregated L3*
1.1.1	Cv - Coefficient variation of rainfall - years	0.26	1	0.33	0.11

1.1.2	Cv,m - Coefficient variation of rainfall - months	0.79	1	0.33	0.11
1.1.3	SR - Storage Ratio	0.96	5	1.66	0.55
1.2	WS - Water Stress	1.08		1	0.33
1.3	SLI - Storage Drought duration length index	3.72		4	1.33
1	**Broad Economy Index**				**2.4**
2.1	WAP - Water productivity in Agriculture	521		4	2
2.2	SSA - Self-sufficiency in Agriculture	4.05		1	0.5
2	**Agriculture Index**				**2.5**
	Economic Water Security (max 10)				**4.9**

**L1, L2 and L3 refers to the score of the three sub-indicators levels established by the AWDO methodology. Thus, L2 result from the average aggregation of L1, if any. The same for L3 and the final AWDO score.*

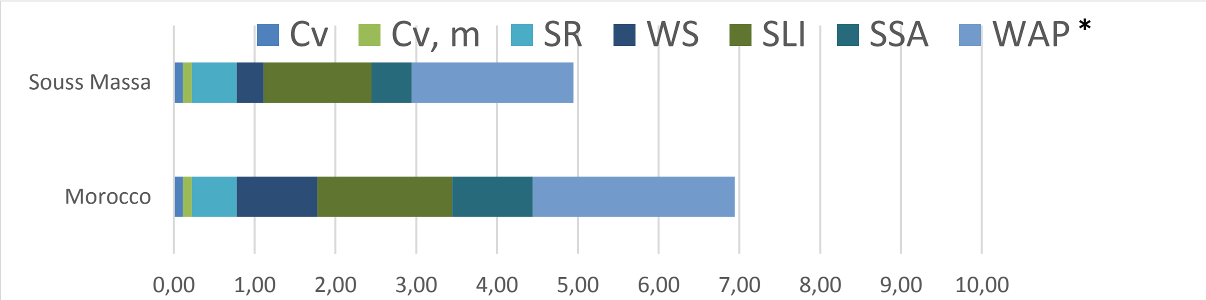

Figure 4. AWDO scores for the sub indicators related with the Broad Economy Index and Agricultural Index for the Souss Massa watershed and the national average value for Morocco.

*where Cv is the Coefficient variation of rainfall between years; Cv,m is the Coefficient variation of rainfall between months; SR is the Storage Ratio; WS is the Water Stress; SLI is the Storage Drought duration length index; WAP is the Water productivity in Agriculture and SSA is the Self-sufficiency in Agriculture.

Figure 5 shows that some of the sub-indicators are far away from their maximum potential score value (red dotted line in Figure 5). The red dotted line represents the maximum aggregated score each sub indicator could get according to the weights established by the AWDO methodology. This is especially true for SSA, WS, Cv,a and Cv,m, where the score obtained is 1. However, not all these sub-indicators affect in the same way the final score, being SSA and WS the sub indicators pulling down the overall score (Figure 5). In the same way, although Cv,a and Cv,m present a very low score, since they are subsequently aggregated into the Reliability sub-indicator, their negative impact is limited.

WS relates to water availability and water demands. As it could be derived from the data provided by the Plan Blueu (El Badraoui and Berdai, 2011), water demand is higher than water availability, translating into a WS of almost 1.1. That means that the Souss-Massa basin requires around 10% more water than the renewable resources. A more in depth analysis reveals that these additional resources are usually coming from groundwater, creating an over extraction of around 167 Mm^3/year. This over extraction is translated into a constant decrease of the water table of all the aquifers located in the basin.

SSA relates the water embedded in the production and consumption of agricultural products by the economic sectors, providing an idea about the dependency of the region from the importation of virtual water from other areas, either from Morocco or outside the country. Although agriculture in Souss-Massa is prominent and consume a large amount of water, the water required to produce the food imported to feed the 2.7 millions of inhabitant of the region is almost 4 times higher than the water related with the local production.

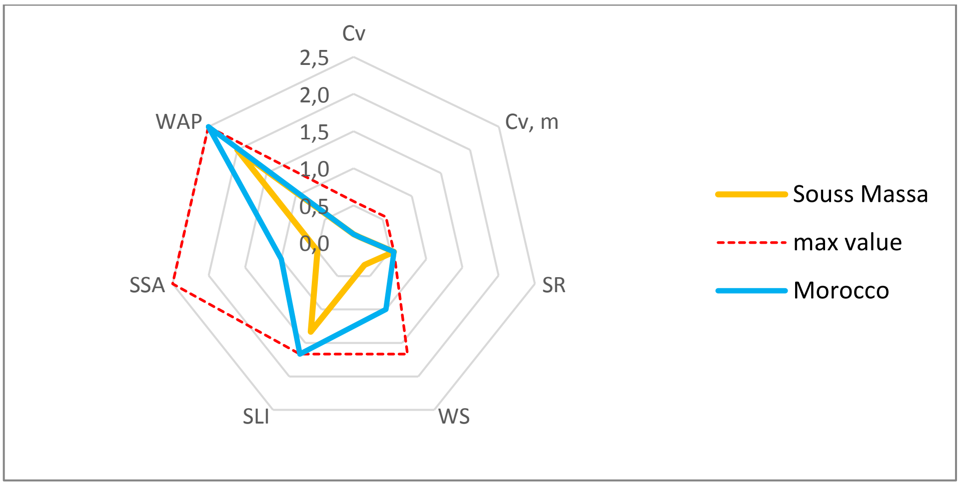

Figure 5. Comparison of the aggregated AWDO scores for the subindicators related with the Broad Economy Index and Agricultural Index for the Souss Massa watershed and the national average value for Morocco.
Red dotted line represent the maximum aggregated value that each sub-indicator could reach according to the AWDO 2016 methodology (see table 1).

4.1.2 Conclusions: Souss-Massa basin

The calculated water security score for the Souss Massa basin is lower than the water security calculated for the whole country, due to a lower water productivity, a higher dependency on the water embedded in the imported agricultural products and the higher water stress, with a water demand higher than the fresh water availability. The latter is only possible thanks to the current over exploitation of the related aquifers, which show a constant decline of the water table. This strategy cannot be applied in the long term, so urgent measures to reduce water consumption and to balance offer and demand are required to guarantee that enough water is available for all the economic activities in the basin. Among these strategies, the use of reclaimed water from the coastal city of Agadir to irrigate high added value products would give a significant contribution to alleviate water stress.

4.2 Characterising Water Stress and Water Security in Cap-Bon and Miliane basin

4.2.1 Results: Cap-Bon and Miliane basin

The Cap-Bon and Miliane basin presents a TRWR of around in 366 Mm^3/year (150 Mm^3/year surface water and 216 Mm^3/year groundwater), while the water demand is estimated in 316 Mm^3/year (CRDAN, 2016). As in most of the cases, agriculture is the higher consumer, with around 275 Mm^3/year (87%). The total irrigated area is estimated in 166,000 ha/year, where irrigation or permanent crops (trees) is the most relevant, followed by cereals and vegetables (ONA, 2012). Irrigation of non-food crops is also remarkable. This figure represents around 40% of the total irrigated area of the country

From the Economic Water Security assessment developed, we can state that the Cap-Bon and Miliane basin get a score of 6.7 over 10 (*Table 4*). This figure is very similar to the score calculated for the whole country (Figure 6) and reveals a moderate to high water security.

As for the whole country, Agricultural Index provides the higher score to the final value. The value is almost two times higher than the score provided by the Broad Economy Index. This is because both WAP and SSA are in very high values (Figure 7). If we compare these results with the national score, we can see a similar trend, although there is a higher WAP for the whole country and a lower SSA. The Cap-Bon and Miliane basin presents a relatively high WAP, with values estimated in around 615 Million USD/Km^3, mainly thanks to the irrigation of vegetables and trees. The dependency on the water embedded in external agricultural product is also low, having the basin a self-sufficiency capacity in Agriculture.

Table 4. Final values calculated and score, Cap-Bon and Miliane basin (Tunisia)

No.	Index descriptor	Score	2016 AWDO Scoring		
			L1*	Aggregated L2*	Aggregated L3*
1.1.1	Cv - Coefficient variation of rainfall - years	0.23	3	1	0.33
1.1.2	Cv,m - Coefficient variation of rainfall - months	0.56	1	0.33	0.11
1.1.3	SR - Storage Ratio	0.85	5	1.66	0.55
1.2	WS - Water Stress	0.86		1	0.33
1.3	SLI - Storage Drought duration length index	4.62		4	1.33
1	**Broad Economy Index**				**2.7**
2.1	WAP - Water productivity in Agriculture	615		4	2
2.2	SSA - Self-sufficiency in Agriculture	0.75		4	2
2	**Agriculture Index**				**4**
	Economic Water Security (max 10)				**6.7**

**L1, L2 and L3 refers to the score of the three sub-indicators levels established by the AWDO methodology. Thus, L2 result from the weighted aggregation of L1, if any. The same for L3 and the final AWDO score.*

An in depth analysis of the Broad Economy Index shows that WS is the sub-indicator with the lower score, since water withdrawal represent around 85% of the TRWR, with almost 100% of the total groundwater renewable resources allocated to different users (CRDAN, 2016). However, thanks to the large storage capacity of the basin, estimated in 309 Mm^3, the basin could surplus the required water during at least 12 months without precipitation, giving a certain resilience to the water dependant sectors.

Although no indicator reaches its maximum potential score value (red dotted line in Figure 7), both WAP and SSA present a very high value (2 over 2.5 according with the AWDO methodology). The red dotted line represents the maximum aggregated score each sub indicator could get according to the weights established by the AWDO methodology. On the contrary, both WS and Cv,a present the lower values, where the score obtained according with the AWDO methodology is 1 (0.11 over 0.55 and 0.33 over 1.66 respectively).

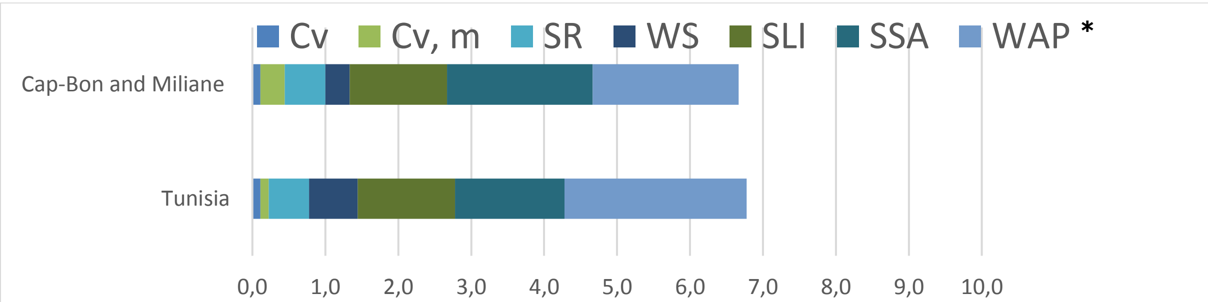

Figure 6. AWDO scores for the sub-indicators related with the Broad Economy Index and Agricultural Index for the Cap-Bom and Miliane watershed and the national average value for Tunisia

*where Cv is the Coefficient variation of rainfall between years; Cv,m is the Coefficient variation of rainfall between months; SR is the Storage Ratio; WS is the Water Stress; SLI is the Storage Drought duration length index; WAP is the Water productivity in Agriculture and SSA is the Self-sufficiency in Agriculture.

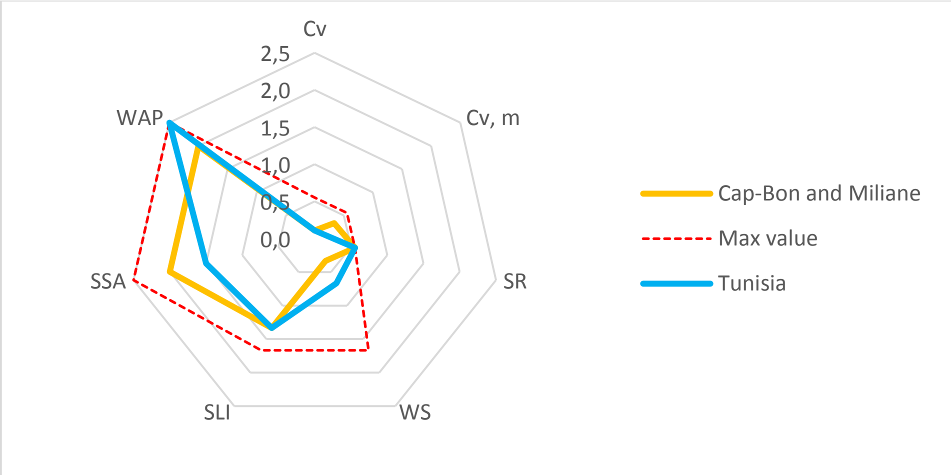

Figure 7. Comparison of the aggregated AWDO scores for the subindicators related with the Broad Economy Index and Agricultural Index for the Cap-Bom and Miliane watershed and the national average value for Tunisia.

The red dotted line represents the maximum aggregated value that each sub-indicator could reach according to the AWDO 2016 methodology (see Table 1).

4.2.2 Conclusions: Cap-Bon and Miliane basin

The calculated water security score for the Cap-Bon and Miliane basin is very similar to the values estimated for the whole country. However, some differences could be depicted, such as a higher water productivity in the Cap-Bon and Miliane basin, and a higher dependency of the latter on the virtual water associated with the agricultural products imported. The strategy to produce high added value agricultural products, mainly thanks to the irrigation of vegetables and trees, reduces the vulnerability of the agriculture sector. However, the large water withdrawal compared with the water availability could cause serious conflicts between agriculture and other economic sectors.

4.3 Water stress and Water Security in North-Eastern Nile Delta sub-basin

As mentioned before, due to the hydrological particularities of the North-Eastern Nile Delta sub-basin, it is not possible to apply the AWDO approach to a scale lower than the national level. This is because water availability on the various irrigation districts of Egypt depends exclusively on the water derived upstream from the Nile River and not on the natural water available. So, to understand better the water security at regional level, a water balance for the North-Eastern Nile Delta sub-basin is compared with the results at national level.

4.3.1 Water balance at national level

The national water balance provides insight on how water in Egypt is flowing. This balance gives an insight to show the agricultural water use in context with the other water users. Other insights regarding water security are gained from the previous executed AWDO framework 2016 at national level (Deliverable 1.2).

When looking into the water resources of Egypt, the most strategic water resource of Egypt is Lake Nasser. However, the drought of 2015/2016 severely affected the availability of water resources. In reaction to this drought, the government put a limit to the cultivation of water-consuming crops like rice.

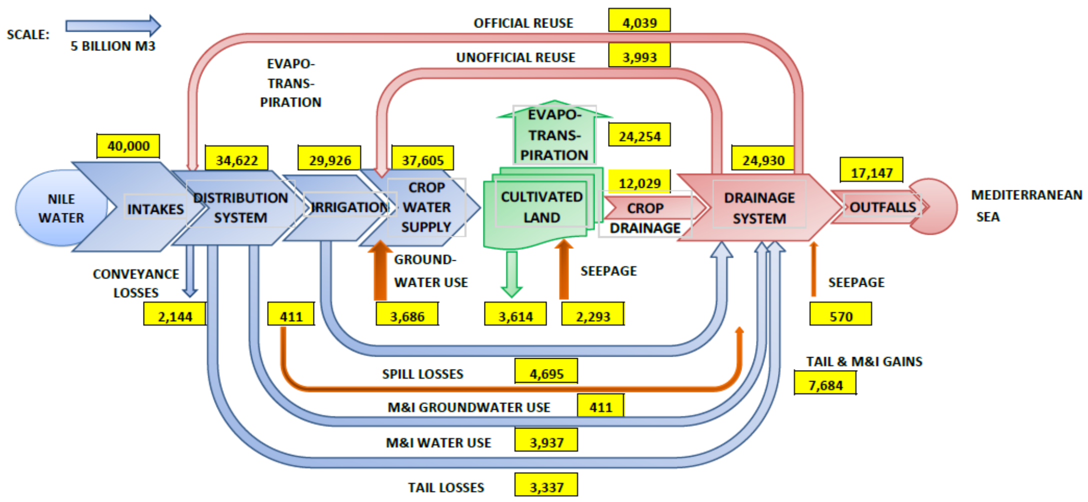

Figure 8. National water balance in Egypt

The annual amount of freshwater available per capita could be used as indicator of water sufficiency. The value of 1000 m^3/cap/year established as critical was reached in 1997 (MWRIARE, 2005). The value in 2015 is estimated in 658 m^3/cap/year, mainly because of strong population growth, from 63 million people in 2000 to more than 90 million people in 2015 (MWRIARE, 2005).

Agriculture is providing 14.5% of Egypt's GDP, 28% of the employment and 20% of export products. 61 billion m3 freshwater resources were allocated to 8.7 million feddan (3.65 million ha) (IMF, 2015). The supplied amount of water is used directly to agriculture, or it has been supplied as reused drainage water. The supplied amount of water in 2015 is equal to an irrigation application of 7000 m3/feddan(1660 mm). This amount gives farmers one to three crop possibilities per year. Of all the water that is supplied to crops, 20% is used for leaching salts and 5% is lost by evaporation. This leaves 1100 mm available for crop water consumption.

In 1997 the cropping intensity was more than 2 crops/year, whereas the current value is 1.8 crop/year (MWRIARE, 2005). The expansion of the agriculture area does not fully cover the explanation of the decline in cropping intensity. Therefore, it is likely that this decrease is also due to the reduced quantity allocated to the agricultural sector, making it less water secure.

For Egypt, an overall Economic Water Security Index of 13.0 (out of 20) has been calculated, which depicts the serious challenge of the country to provide water security to satisfy the economic sectors. Within this study, it is the lowest score in comparison to Morocco or Tunisia. The major difference to both Morocco and Tunisia is the Agriculture index, with a value of 1.5 over 5. This is because of the low value of the water productivity in agriculture and the high dependency on external agricultural products with a large water footprint. The rest of the indicator scores are comparable.

4.3.2 Water balance at North-Eastern Nile Delta sub-basin: Bahr Baqr drain

The water balance of Table 5 shows that there is a gap of 2162 Mm3/y. The biggest contributor to the inflow is the agricultural drainage and the biggest contributor to the output is the outfall from Bahr Baqr drain. However, the biggest user of water are the Armed Forces. This volume is used to expand the agricultural area belonging to the Armed Forces, giving a ratio of water use of around 70%. Looking at the AWDO approach and scoring table, it gives a water stress (WS) value of 2 out of 5.

Comparing the local value of WS with the national scale value (1 out of 5), we can observe that the considered sub-basin is slightly less water stressed than the entire country. However, the score is on the low side and still severe water stress is occurring on local scale.

As calculated, the water quantity is not sufficient, leading to water stress. It is also highly likely that the water quality is not sufficient for agricultural purposes. This is because the water that can be used from the Bahr-Baqr drain is of low quality as it contains drainage and sewage water of the eastern part of Cairo. The treated wastewater is only 7% of the total inflow, whereas the drainage and municipal & industrial return flows are 93% of the total inflow.

Table 5. *Water Balance relative to Bahr Baqr drain*

IN	Volume	OUT	Volume
1.Gabal Asfar (wastewater treatment plant)	182.5 Mm^3/y	1.Open water evaporation	p.m.
2.Agricultural drainage	1546 Mm^3/y	2.(Potential) Armed forces	1825 Mm^3/y
3.Municipal& Industrial return flows	928 Mm^3/y	3.Outfall Bahr Baqr drain	2891 Mm^3/y
4.Seepage	3 Mm^3/y	4. EB13	107 Mm^3/y
Total	**2660** Mm^3/y		**4822** Mm^3/y

4.3.3 Conclusions

Egypt features a different situation than the two other countries (Morocco and Tunisia). Looking at the national water security, Egypt has a value of 13 (out of 20), which is a low score. This is mainly due to high water stress. The water stress has a score of 1 (out of 5) which gives an indication that more than 80% of the fresh water resources is used. The water stress is high because of high withdrawal. Looking at the local scale (Bahr Baqr drain), one can see that the largest consumer are the armed forces, because of extension production areas. Nevertheless, the analysis reveals that the local situation is slightly better than the national one, with a water stress value of 2 (out of 5). However, the difference between the two-water stresses is relatively small.

Inconsistency in the water balance raises further questions related to the setup of the water balance. The gap reveals the dependency of the model on several assumptions. To increase the consistency of the water balance, more knowledge is needed on the actual groundwater consumption. This would help to improve the Water Balance, but the technical realization is nearly impossible, as groundwater measurements/estimations are very challenging in Egypt, because of the large amount of unregulated users, among other elements. In this view, it remains a challenge to link national and local scale.

5 Conclusions

A water security assessment is a powerful tool to understand the water related issues and hazards of a specific area. It combines the information provided by several sources into a grouped and standardised value. This easy to understand score could be used for awareness raising at different levels, from citizens to policy makers, being the key to initiate measures and to derive the right policy instruments to improve the water situation. When these evaluations are applied on a broader geographic scope, they also allow to compare the water related situation of various regions. Similarly, when a water security assessment is developed on a regular basis, the effect of different policies on the evolution of water security could be assessed.

A number of different efforts have been made in the past to quantify Water Stress, Water Vulnerability or Water Security, leading to a large number of approaches, indicators and levels. Among all of them, the Economic Water Security from the 2016 AWDO framework has been used in MADFORWATER, in order to allow a more consistent comparison of information both with previous and forthcoming international studies.

As documented in Deliverables 1.2 and 1.4 of MADFORWATER, the water security assessment could be applied at various scales, providing different insights when those scales are connected. On large scales, water security helps to identify and prioritise the right policy instruments to improve the water situation. Moreover, it provides an insight on how the different economic sectors would be affected by potential changes on the current situation. However, when the impact of individual measures needs to be evaluated, the assessment at a national scale is insufficient, and an analysis at smaller scales is required. River basins would be the minimum scale to assess water security, since every measure taken will affect the water balance. However, depending on the basin zone in which the measures are implemented (highlands or lowlands, for example), the effect on the overall water security could vary.

The suitability of the sub indicators is also dependant on the scale, some adaptation being required when we move from one scale to another. The use of a nested approach allows combining both the elaboration of spatial explicit water resources related indicators (Broad Economy Index) with indicators coming from statistical sources (Agriculture, Industry and Energy Indexes). However, this is usually hampered by the non-availability of statistical data at lower levels and of course with the difficulties to extrapolate the regional (or national) information within the boundaries of a river basin. On the other hand, not all the sub indicators used at national level keep the same meaning at lower scales. This is the case of the energy related indicators, since the electricity network is usually interconnected at national level, not making any sense to differentiate the source of the energy on scales lower than the country.

Indicators as agricultural water productivity and water exploitation index can be used as anchor indicators, using these sub indicators for relating new situations or scenarios to the overall context at river basin and national scale.

In some cases, such as Egypt, where all water within the Nile Valley and its Delta originates from the Aswan High Dam, a differentiation of available natural water resources in the different sub regions will not deliver sensible additional information. In such cases, a detailed water balance could provide a good insight to assess water security on lower scales.

Wastewater reuse is usually considered as a direct way to reduce water risk, by putting in value new water resources for several uses. For example, a well-planned water reuse project could alleviate the water related issues of farmers in a local situation, by providing a constant resource less dependent on climate variability. This will also increase the security of those farmers and the related consumers both in terms of quality and health. However, it does not increase the total amount of water at basin level that can be consumed by evapotranspiration.

Wastewater reuse projects are usually related with large investments and therefore linked with a higher valorisation of water by users. A (higher) price of water forces farmers to invest in better technologies to increase water efficiency: technology can improve the agricultural water productivity.

When wastewater is used to replace the abstraction of freshwater resources - usually related with an indirect water reuse in semi-arid regions -, it will improve the water quality in rivers, minimizing the risk related with water quality. In some cases, such as downstream sources of wastewater close to the sea, reuse of wastewater traditionally discharged to the sea may offer opportunities to increase agricultural production without affecting the upstream flow. But it is important to note that if wastewater reuse is not well planned, and if it is seen as an additional water source - for example to expand the irrigated areas – rather than a mean to reduce the current abstraction of freshwater resources, the impact on water security will be quite limited.

In summary, interventions for reusing wastewater can be of strong local impact to improve the reliability of local water supply, to stimulate technological developments, and to reduce the discharge of pollutants to rivers and the sea. On the other hand, in the absence of a well-designed basin-scale water management, the overall impact of wastewater reuse at basin scale can be quite limited.

6 Bibliography

Abdel Gawad, S.T., M.A. Abdel Khalek, D. Boels, C.W.J. Roest, M.F.R. Smit and T.N.M. Visser, 1993. Training Manual SIWARE Model. Drainage Research Institute and DLO Winand Staring Centre.

AWDO, 2016a. Asian Water Development Outlook 2016: Strengthening Water Security in Asia and the Pacific. Asian Development Bank.

AWDO, 2016b. Description of Methodology and Data: Asian Water Development Outlook 2016: Strengthening Water Security in Asia and the Pacific. Asian Development Bank.

Chouchane, H., Hoekstra, A. Y., Krol, M. S., & Mekonnen, M. M. (2015). The water footprint of Tunisia from an economic perspective. Ecological indicators, 52, 311-319.

CRDAN, 2016, Commissariat Regional au Developpement Agricole Nabeul, Rapport annuel 2016.

El Badraoui, M.H., Berdai, M., 2011. Adaptation du système eau-énergie au changement climatique: Etude nationale-Maroc. Rapport Finale. Plan Bleu. Centre d'Activités Régionales PNUE/PAM.

Eriyagama, N., Smakhtin, V. Y., & Gamage, N. (2009). Mapping drought patterns and impacts: a global perspective (Vol. 133). Iwmi.

FAO, 2016. AQUASTAT database. Food and Agriculture Organization of the United Nations, Rome, Italy.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., Michaelsen, J., 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Scientific Data 2, 150066.

Gassert, F., Luck, M., Landis, M., Reig, P., & Shiao, T. (2014). Aqueduct global maps 2.1: Constructing decision-relevant global water risk indicators. World Resources Institute.

Holmatov, B., Lautze, J., Manthrithilake, H., Makin, I., 2017. Water security for productive economies: Applying an assessment framework in southern Africa. Physics and Chemistry of the Earth, Parts A/B/C 100, 258-269.

IMF - International Monetary Fund (2015). Country report No. 15/33.

DRI/SC-DLO. 1995. Reuse of drainage water in the Nile Delta; monitoring, modelling and analysis; final report Reuse of Drainage Water Project. Reuse Report 50. DRI, Cairo and SC-DLO, Wageningen.

Madforwater – Deliverable 1.2 Water stress and Water Vulnerability indicators and maps, 2018. Development and application of integrated technological and management solutions

FOR wastewater treatment and efficient reuse in agriculture tailored to the needs of Mediterranean African Countries

MADFORWATER – Deliverable 3.4 Final report on the water & crop allocation model, 2019. Development and application of integrated technological and management solutions FOR wastewater treatment and efficient reuse in agriculture tailored to the needs of Mediterranean African Countries.

MAFRDF, 2017. Statistiques de la production vegetale, campagne 2013-2014, 2014-2015, 2015-2016, in: Ministry of Agriculture, F., Rural Development and Forest of Morocco: Direction de la Stratégie et des Statistiques (Ed.).

Masutomi, Y., Inui, Y., Takahashi, K., & Matsuoka, Y. (2009). Development of highly accurate global polygonal drainage basin data. Hydrological Processes: An International Journal, 23(4), 572-584.

MWRIARE - Ministry of Water Resources and Irrigation of the Arab Republic of Egypt, 2005. Water for the Future, National Water Resources Plan 2017.

ONA, 2012, Observatoire National de l'Agriculture

R-Core, T., 2013. R: A language and environment for statistical computing.

Rijtema, P.E., M.F.R. Smit, D. Boels and S.T. Abdel Gawad, 1994. Formulation of the water and salt distribution model WATDIS for surface water systems. Reuse of Drainage Water Project. Reuse Report 23. DRI, Cairo and SC-DLO, Wageningen.

Roest, C.W.J., RE. Rijtema, M.A. Abdel Khalek, D. Boels, S.T. Abdel Gawad and D.E. El Quosy, 1991. Formulation of the on-farm water management model ' FAIDS'. Report 24, Reuse of Drainage Water Project. DRI, Cairo and SC-DLO, Wageningen.

Schyns, J.F., Hoekstra, A.Y., 2014. The Added Value of Water Footprint Assessment for National Water Policy: A Case Study for Morocco. PLOS ONE 9, e99705.

Sijtsma, B.R., D. Boels, T.N.M. Visser, C.W. Roest and M.F.R. Smit, 1995. Simulation Water management in the Arab republic of Egypt; SIWARE Users' manual, version 1.2. Report 27, Reuse of Drainage Water Project. DRI, Cairo and SC-DLO, Wageningen.

Stahl, R., Ramadan, A. B., & Pimpl, M. (2009). Bahr El-Baqar drain system/Egypt environmental studies on water quality. Part I: Bilbeis drain/Bahr El-Baqar drain.

Svoboda, M., Hayes, M., & Wood, D. (2012). Standardized precipitation index user guide. World Meteorological Organization Geneva, Switzerland.