Impact Evaluation of Sustainable Land Management Practices for Achieving Land Degradation Neutrality in Tunisia

Technical report

Creating Spatial Data on Sustainable Land Management Practices in two Pilot Sites in Tunisia (Northern Africa)

Diwediga Badabate
Fradi Fajr
Quang Bao Le

July 2017

Summary

Many efforts have been invested in the Dry Areas to combat land degradation and desertification. Different strategies and approaches for conserving soil and water and restoring degraded lands have been developed by local, national and international agents to synergise efforts towards land degradation neutrality achievement. Tunisia is a dryland country facing a high risk of land degradation over more than 50% of its territory. It is a country with high investment programs for soil and water conservation (SWC), and large level adoption of SLM practices. With some successes and failures experienced, there are currently no sufficient information that could allow knowledge based assessment of such investments and commitments. The need for up- and out-scaling success stories is challenged by the lack of real time spatial data on SLM practices. In this work, the main objective is to make an inventory and document the widely adopted SLM practices in Tunisia, and develop a spatial database of such practices for impact assessment and scaling out/up. The work was based on literature review, field based data, secondary data from national institutions, and high resolution satellite images. The work was conducted in two pilot sites (Medenine governorate in South-Eastern and Zaghouan governorate in Centre-North) located in different socio-environmental contexts of Tunisia. Many technologies exist in the context of Tunisia, showing a high diversity of initiatives to combat land degradation and ensure sustainable lands. In this works, eighteen (18) SLM practices were investigated in two pilot sites. This diversity emerges from the synergies from land users, researchers, policy-makers and donor agencies, in order to improve land management, conservation and restoration in arid areas of Tunisia. Each specific context revealed specific SLM practices, even though there exist some similarities. Some practices are very common, and widespread whereas others are very locally applied. These SLM practices target specifically soil and water conservation, the control of sand dune mobility, the improvement of degraded rangelands, the collection and storage of runoff water, and the improvement soil surface cover through tree plantation. Based on field observation, there is a high adoption level, which should be encouraged and supported by scientific documentation for policy orientation in order to achieve land degradation neutrality in Tunisia.

TABLE OF CONTENTS

List of figures

List of photos

List of tables

Acronyms and abbreviations

ALUS	Aggregated Land Use Systems
CES	Conservation des Eaux et des Sols
CRDA	Commissariat Régional au Développement Agricole
DGACTA	Direction Générale de l'Aménagement et Conservation des Terres Agricoles
ESRI	Environmental Systems Research Institute
GeOC	Global Geo-Informatics Options by Contexts
GIS	Geographical Information System
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit (English: German Corporation for International Cooperation)
GPS	Geographical Information System
IRD	Institut de Recherche pour le Développement
LADA	Land Degradation Assessment in Dry Areas
OxC	Options by Contexts
QGIS	Quantum GIS software (freeware)
SAEZ	Socio-Agro-Ecological Zones
SLM	Sustainable Land Management
SWOT	Strengths, Weaknesses, Opportunities and Threats
WebGIS	Web-based Geographical Information System
WOCAT	World Overview of Conservation Approaches and Technologies

1. Introduction

Sustainable Land Management (SLM) has been promoted world-wide as a concept to build viable landscapes, and strong and resilient people and communities. As a major dimension in achieving the Sustainable Development Goals (SDGs), especially the SDG 15, there is a need to develop and maintain database that would be important for evaluating SDG indicators at different scales. The 2030 Agenda for Sustainable Development Goals (SDGs) requires solid framework of indicators and statistical data to monitor progress, inform policy and ensure accountability of all stakeholders. Developing and maintaining information system on practices promoting SLM, and subsequently, all the related benefits, is a practical solution towards the achievement of the land degradation at different scales. As desertification and land degradation are complex processes with increasing concerns, forms and impacts at various scales, an alternative to support efforts to combat the phenomena is to constantly develop and maintain easy to measure and perceptible monitoring indicators that could help in impacts assessment of mitigation efforts. Multiple benefits can be derived from improving information on land management at local and landscape levels: food security, resilient communities, combating land degradation and desertification, reducing resource-related conflicts, reducing disaster risks, adaption to and mitigation of climate change, preservation of several landscapes, biodiversity and ecosystem services.

Feeney *et al.* (2001) described the need for spatial data provision as a key component in supporting appropriate decision-making for sustainable land management. Based on the capability of the GIS-based data to integrate different aspects (socio-economics, biophysical, institutional, etc.), spatially explicit SLM options could be more attractive to the donors and policy makers, the provision of spatial data will continuously encourage comprehensive spatial documentation and evaluation throughout specific attributes monitoring at different scales. Spatial distribution i.e. space allocation matters considerably in the land use systems and the adoption of SLM. This situation raises the need to expand the knowledge on SLM adoption to the development of spatially-explicit database on SLM for better site-specific and landscape-specific as well as option-specific impact assessment. In the perspectives of out- and up-scaling SLM technologies and efforts, spatial information, potential impacts and level of adoption are important pathways and strategies to ensure better visibility that meets the core principles of SLM (i.e. productivity and protection of natural resources, coupled with economic viability and social acceptability (Schwilch *et al.*, 2011). In this regard, a knowledge on these key principles would better allow the promotion of SLM towards the achievement of LDN. Numerous SLM options are adopted in different contexts with less attention to meeting these core principles. However, there has been relatively little documentation or evidence of the spatial information on the exact locations of the SLM practices in different contexts and scales, relatively important for supporting better and timely decision making. This is important to synergise and consolidate efforts to efficiently address land degradation, standing on solid database support.

GIS based data infrastructures have been successfully applied in various domains (urban planning, rural land use, public transport management, etc.), encouraging hence efforts to develop spatial database on SLM could render more effective the monitoring of SLM adoptions at micro, meso and macro-scale worldwide, through the data management and processing, spatial analysis and visualisation, as well as policy design, decision making, site suitability analysis for developing participatory landscape design and re-design of more benefits from SLM. Besides the global World Overview of Conservation Approaches and Technologies initiative (WOCAT) that has developed standardized tools and methods for documenting, evaluating, and assessing the impacts of SLM practices at global scale, the proper knowledge on site-specific SLM adoption and their spatial configuration are still lacking. These important aspects of promoting good options at local and global, for out-scaling and up-scaling still need more insights to offer solid basis and pathways for monitoring SLM adoption dynamics, their impact assessment and support decision-making process. The spatial explicit GIS database could increase the operational framework for better orientation based on the qualitative and quantitative data continuously and regularly updated.

2. Contextual settings of Tunisia and the pilot sites

Tunisia is in the Northern Africa in the Mediterranean basin between 32˚ - 38˚ N and 7˚-12˚ E. It covers an area of 163 610 km^2. The country is bordered by Mediterranean Sea at North and East, Libya Arab Republic at the South-Eastern parts, and Algeria Republic in the West (Figure 1). The biophysical and socio-economic information below are retrieved from the national environmental profile (Anonymous, 2012). The country has 24 governorates, which are the main administrative units, divided into 264 municipalities/delegations. The population is about 10.5 million inhabitants of whom 70% are settled in coastal areas. Tunisia has about 1300 km coastal line with the Mediterranean Sea. Great part of the national lands has arid climate. The climate is influenced by oceanic and Saharan winds as well as the mountain chain “Dorsale Tunisienne”. In the north, the climate is Mediterranean type, while it is semi-arid in the central part and arid in the south. Mean temperature over the country vary between 12 ˚C in December and 30 ˚C in July. Mean annual rainfall is 1000 mm in the north, about 380 mm in the centre, and 100 mm in the extreme south-west. The rainfall is mostly concentrated between October and March. Evapotranspiration is high and reaches 1200 mm in the north and 1800 mm in the south. Relief is multiform and elevation reaches 1544 m above sea level in the Dorsale Tunisienne. Terrestrial ecosystems comprise forest lands in the north, steppes in the south-central parts. In the southern areas, landscapes are dominated by sparse steppes with some isolated patches of humid vegetation specific to water points. This mosaic of landscapes in combination with the climate patterns define the land use systems across the country. The northern areas are mostly agro-sylvo-pastoral whereas the centre and the south are mostly agro-pastoral and pastoral, respectively. Main crops are cereals (wheat mostly), tree crops (olive, almond), forage crops, and market gardening. Animal husbandry concerns mainly small ruminants (sheep, goats) and some poultry and dairy cows. Fishing is highly developed with a41 fishing harbours and 165 fish transformation plants. The environmental risks in the country are mostly floods, droughts and forest fires. Tunisia is known as a country with high level of land degradation associated with the harsh climatic conditions.

In the context of this project, focus was given to Medenine governorate (South-East Tunisia) and Zaghouan governorate (Centre-North Tunisia). The first is the semi-arid to arid environment dominated by agro-pastoralism. Focus was mostly on Medenine Governorate (Southern Tunisia). It is located between the latitudes 32˚15’12” and 33˚25’47” N, and longitudes 10˚35’59” and 11˚35’54” E. The other site was mostly a sub-humid to humid context with agriculture-dominated landscapes (in the Centre Northern Tunisia). The focus was on the Zaghouan Governorate located between latitudes 36˚16’15” and 36˚24’2” N, and longitudes 10˚02’23” and 10˚21’60” E. In overall, some mapping attempts were done to partially cover the surrounding governorates of each of the pilot sites as mentioned above.

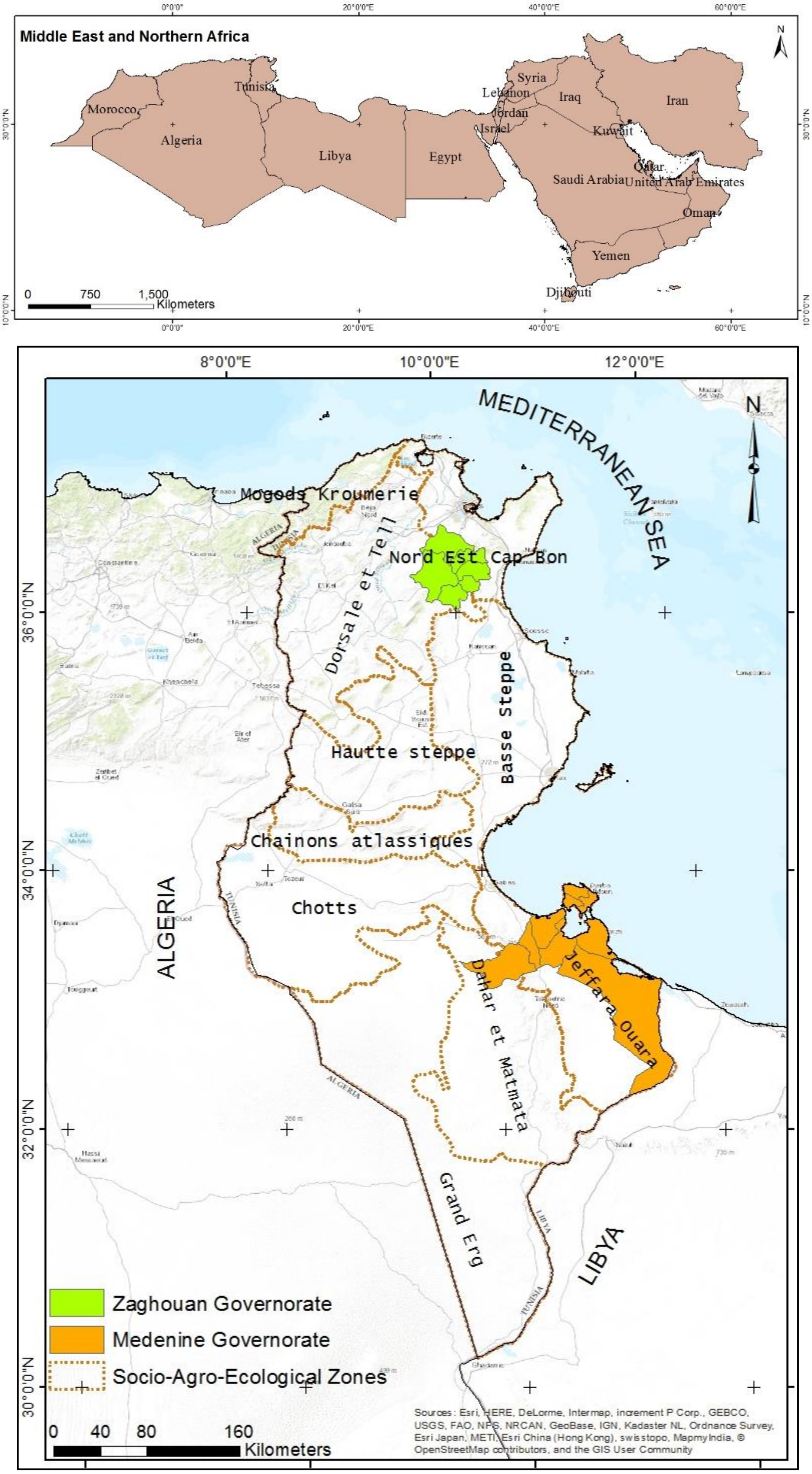


Figure 1. Map of the National lands of Tunisia showing socio-agro-ecological zones

2.1. Overall workflow

This work is undertaken to provide broad distribution of some SLM practices in two pilot sites in Tunisia. It was basically developed following three steps:

- Primary and secondary data sources (see section 2.2). This step focused on the different data used in this work.
- Documenting the SLM OxC technologies using the standardised Excel template (Section 2.3)
- Mapping and evaluation of the SLM techniques based on available datasets (Section 2.4). The methodological approach for mapping the SLM techniques was the focus of this step.
- Organisation of the SLM database based on the SAEZ and ALUS (i.e. aggregation of SLM techniques based on the combination SAEZ x ALUS) (Section 2.5).

For visualisation purpose, a sample of the the mapped SLM were uploaded to the WebGIS platform.

2.2. Data types and sources

2.2.1. Selection process of SLM practices in Tunisia

The approach used for the selection of the SLM to be mapped was two-stepped. First, there was a prior identification of SLM technologies available for Tunisian contexts. This list is based on literature information and helped to have an overview of the common SLM practices in Tunisia Next, based on this list, a field work and sound in-depth information retrieval and fieldwork preparation during which more data were collected to serve mapping the SLM at the sites. This was complemented by information on site from the local services of soil and water conservation.

2.2.2. Field-based data

They are mainly GPS coordinates and field photos of the SLM techniques collected during field visits in March 2017. The data collection was based on a mixed approach (both qualitative and quantitative approaches). On qualitative angle, some descriptive data/information were collected through direct observations, group discussions with SLM adopters (land users, field technicians, administration officers). This information basically facilitated the understanding of some SLM principles/approaches, unexpected impacts perceived and examples of success case studies/stories. This is assimilated to a rapid appraisal of the SLM technologies in rural Tunisia. Quantitative aspects concerned, if available, some specific information on the costs of SLM implementation, the implementation years, and the collection of physiographic data (sites and landscape features, spatial data). Both approaches were simultaneous and lasted 6 days at both sites (3 days per site), and helped in exploring, understanding, and getting overview on SLM technologies.

(i) Archived data of SLM technologies

Mainly, information on SLM technologies were retrieved from the World Overview of Conservation Approaches and Technologies (WOCAT) online database and the report of Land Degradation Assessment in Dry Areas (LADA) in Tunisia (Taamallah *et al.,* 2010). Common attributes of SLM technologies and approaches were cross-retrieved from these two sources.

(ii) Literature-based information

Published and grey literature (from technical/evaluation/monitoring reports, scientific publications, etc.) were consulted and reviewed for documenting/enriching the attributes of some SLM technologies. The technical documents were mostly from the Soil and Water Conservation Office (Conservation des Eaux et Sols - CES) of Zaghouan governorate, and concerned the annual monitoring reports of hill reservoirs (dams and lakes) for the period 1994 – 2006, except for the pairs 1998-1999 and 2001-2002 (DGACTA and IRD, 1996, 1997a, b, 1999, 2001, 2002, 2007, 2008a, b, 2009).

(iii) High resolution images

High resolution Earth observation data from Google Earth engine were used for the identification of SLM implementation areas. Even though these images are of fine resolution.

(iv) Other secondary spatial data

Some existing GIS data were collected from local institutions in Tunisia. Specifically, the data were collected from the Zaghouan Office of Soil and Water Conservation (Direction de la Conservation des Eaux et Sols – CES). The data consists of the spatial distribution of some gabion check dams, hill reservoirs (lakes and dams) of the whole Governorate of Zaghouan. In addition, data on mechanical bench terraces covering the Rmel catchment were collected from the same institution. These data served as reference for the harmonisation step prior to the mapping of the SLM technologies in the study site of Zaghouan.

2.3. Filling in the standardised SLM OxC templates

Standardised SLM OxC templates were used to document relevant information on SLM technologies in Tunisia. Information are retrieved from available literature mainly in the WOCAT database (Section 2.3) to fill in the templates. The SLM templates are structured in six (06) main parts:

- Name of the SLM technology

- Description of the SLM technology
- Purpose and classification of the SLM technology
- Geographical location, extent and socio-ecological context/environment of the technology
- Technical specifications, inputs and costs of the technology
- Impacts and influencing factors related to the SLM technology

Based on data/information availability, the SLM templates for the various technologies are filled in at different levels.

2.4. Mapping the SLM technologies

The mapping was designed to provide a comprehensive spatial distribution of implemented SLM technologies in two sites in Tunisia. The Figure 2 presents the overall workflow of the mapping process. The main aspects covered during the mapping and database documentation on SLM technologies are the following: (i) Visual interpretation and feature identification; (ii) Vector data creation and processing; (iii) Attributes management and quality insurance (data cleaning); (iv) Generation of metadata and other information (visual data, technical draw); and (v) Reporting and narration.

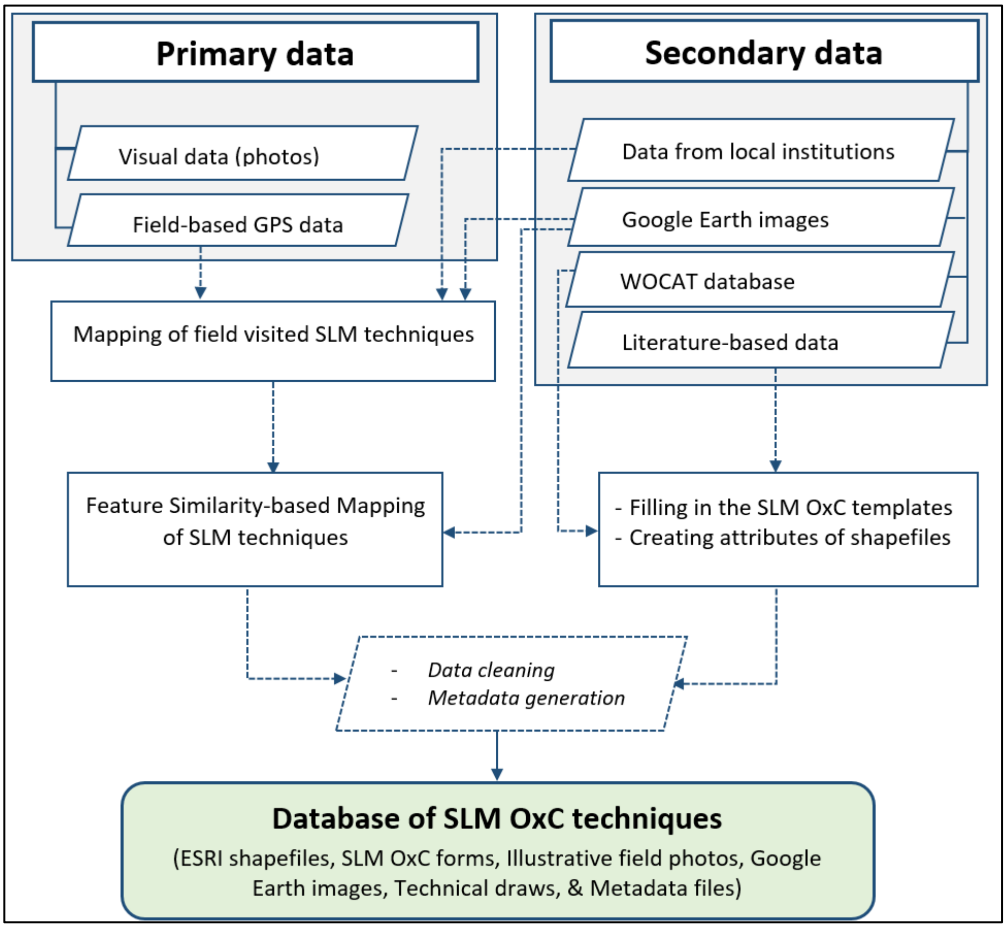


Figure 2. Step flow in GIS database generation on SLM technologies in Tunisia (Source: Authors)

The feature identification was possible through visual interpretation of the high-resolution satellite images from Google Earth Engine through QGIS freeware using OpenLayers Plugin. The combination of different data, especially field-based GPS collected data and resource data from CES-Zaghouan was useful for feature identification through visual interpretation of Google Earth images. In general, the overall view at the landscape levels was possible at a scale of 1/10 000. For the identification of specific boundaries of the SLM technologies of interest, the scale was improved to 1/5 000 and 1/2 500. These finer scales enabled better digitising process for the vector data creation regarding the various SLM technologies. Two types of vector geometry were used during digitising process (Figure 3). First, polygons were used to represent SLMs with large spatial coverage (e.g. "mechanical terraces", "Tabia systems", etc.). Point geometry type was used to represent point-like SLM features (e.g. "recharge wells", "cisterns", etc.). Based on landscape feature similarity, SLM were digitised landscape-wide, based on the geospatial information collected through GPS and some visual data (field photos). Caution was given to ensure accurate feature discrimination since the approach is basically visual (object-based) analysis. SLM practices were digitized as much as possible in the two selected sites. Caution was given to stake into account similar climatic or socio-agro-ecological zones in which the mapped SLM are implemented. The filled in SLM templates (see Section 2.3) were then used to generate associated attributes data of the mapped SLM (in ESRI shapefile). Furthermore, metadata were generated for the GIS database.

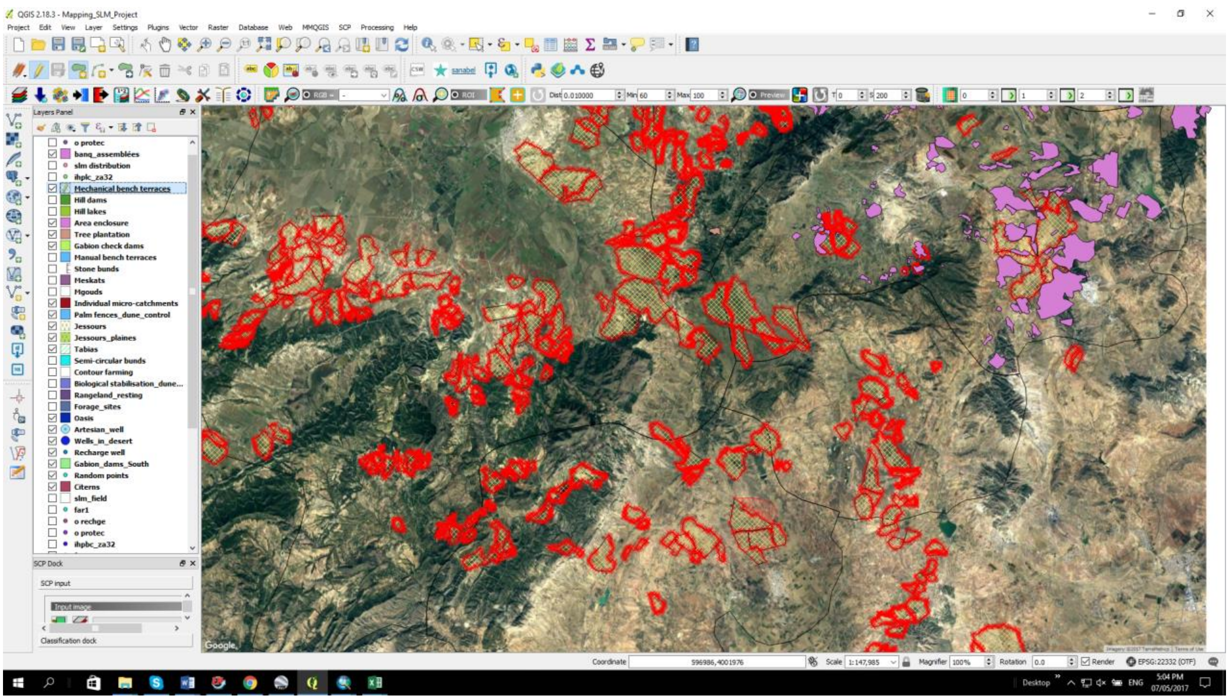


Figure 3. Overview of digitizing process of SLM practices **(**Source: mapping screenshot**).**

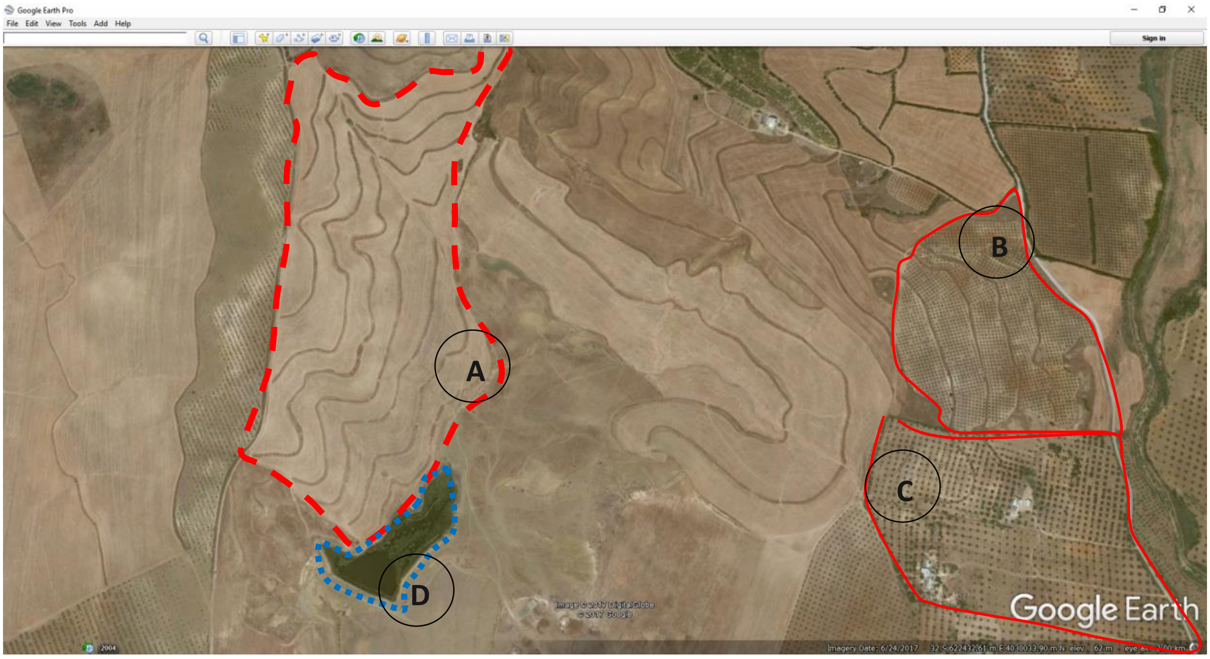


Figure 4. Examples of digitizing identified SLM practices in Google Earth engine (Source: mapping screenshot). **A** = Mechanical bench terraces for cereal crops; **B & C**= Mechanical bench terraces for tree crops for two farm fields of different ages; **D** = Hill reservoirs for irrigation of surrounding farm plots.

2.5. Organising the diversity of SLM technologies across contexts

The following strata were considered for SLM categorisation:

- Socio-Agro-Ecological Zones (SAEZ) adopted from MEAT-Tunisie (2007) and Anonymous (2012): In total, 6 SAEZs were covered by the mapped SLM technologies: SEAZ2, SAEZ3, SAEZ4, SAEZ5, SAEZ8 and SAEZ9.
- Aggregated Land Use Systems (ALUS) (DGACTA, 2008): Two ALUS were frequent: ALUS 1 and ALUS 2
- Administrative units: two governorates mainly: Zaghouan in Centre-North and Medenine in South-Eastern

3. Mapping outputs

3.1. Overview of the Sustainable Land Management Practices in the two sites

The main database of the SLM technologies (18 in total) for both sites/contexts, contains the following files:

- GIS shapefile data (ESRI format) for each SLM technology
- Google Earth image (.jpg format) for showing the patterns of each SLM technology. The images are described by a short title, the location, the scale

- 1 to 2 field photos (.jpg format) of the SLM technologies. Each field photo is described by providing a short caption, the source and the date taken.
- Filled in standardised SLM OxC form (.xlsx format) for each SLM technology;
- Technical sketch (.jpg format) for some SLM technologies (based on the availability). The source and some technical specifications (if available) of the sketch are mentioned.

Overview of the SLM practices is provided in the tables beneath each subsection which shows the repartition of the SLM based on the SAEZ, ALUS and administrative units (governorates). A short description of each SLM is provided as well.

3.1.1. Techniques targeting specifically water and soil conservation

Table 1 gives an overview of the SLM technologies targeting soil and water conservation per socio-agro-ecological context and land use system.

Table 1. SLM practices targeting soil and water conservation (SWC)

SLM ID	**Techniques**	**Socio-Agricultural Ecological Zone (SAEZ)** (as defined in ANNEX 1)	**Aggregated Land Use System (ALUS)** (as defined in ANNEX 2)
1.1.	Jessour	SAEZ8; ZAEZ9	ALUS2
1.2.	Tabia	SAEZ8; SAEZ9	ALUS2; ALUS5
1.3.	Mechanical bench terraces	SAEZ2; SAEZ3	ALUS1 ; ALUS2; ALUS3
1.4.	Manual bench terraces	SAEZ2	ALUS2
1.5.	Stone bund terraces	SAEZ2; SAEZ9	ALUS2; ALUS7
1.6.	Gabion check dams	SAEZ2; SAEZ3; SAEZ8; SAEZ9	ALUS1 ; ALUS2
1.7.	Individual micro-catchment	SAEZ2	ALUS2

Note: Socio-agro-ecological zones (SAEZ1 = Mogods and Kroumerie ; SAEZ2= Nord Est Cap Bon ; SAEZ3 = Dorsale et Tell ; SAEZ4 = Basse steppe ; SAEZ5 = Haute steppe ; SAEZ6 = Chainons atlasiques ; SAEZ7 = Chotts ; SAEZ8 = Dahar et Matmata ; SAEZ9 = Jeffara- El Ouara; SAEZ10 = Grand Erg) and the agrggegated land use systems (ALUS1 = Irrigated Crops; ALUS2 = Rainfed crops; ALUS3 = Non-irrigated agro-pastoralism; ALUS4 = Irrigated agro-pastoralism; ALUS5 = Pastoralism on bare soils; ALUS6 = Pastoralism on shrub lands; ALUS7 = Natural zones ; ALUS8 = Urban areas; ALUS9 = Parks and natural reserves; ALUS10 = Ramsar sites).

- **Jessour technique**

Mostly developed in the SAEZ8 and SAEZ9, Jessour technique is the most ancient technology for collecting the water of the runoff watercourses (Photo 1 A & B). It is a wise traditional technique for water and soil conservation technique in south-eastern Tunisia, especially in arid highlands. The purpose is to collect the runoff water for irrigation of tree and cereal crops. It is an earth dam usually consolidated with stones in the mountain slopes to hold back the runoff water. This technology provides a good runoff water management in the area where applied as well as a good soil protection from water erosion. It is profitable for farmers. Therefore, it is widely adopted in the Matmata mountain chain from ages.

Photo 1. Jessour with olive trees in a hilly landscape (Left) and a gentle slope waterways (Right) in the Beni Khedache (Medenine Governorate, Tunisia) (Photo: Diwediga B. & Fradi F., March 2017)

- **Tabias system**

Tabias are a typical system of runoff harvesting on sites with deep soils in the semi-arid and arid areas. They are earthen structures built at the foothills and piedmont areas (Photo 2). The tabia technology is like the jessour system but is used in the gently-sloping foothill and piedmont areas. It is a relatively new technique, developed by mountain dwellers who migrated to the plains. Tabias, like jessour, comprise an earthen dyke (50 - 150 m in length, 1 - 2 m in height), a spillway (central and/or lateral) and an associated water harvesting area. The differences between the tabia and the jessour systems are that the former contains two additional lateral bunds (up to 30 m long) and sometimes a small flood diversion dyke (Mgoud). Besides their water harvesting qualities, Tabias also have a positive effect on soil erosion and groundwater recharge.

Photo 2. Tabia system in Medenine governorate. Long bench half-bent with its basin for rangeland improvement (Left), and healthy green olive trees on bench where soil depth is high and water infiltration very high (Right) (Photo credit: Diwediga B. & Fradi F., March 2017)

- **Mechanical bench terraces**

Mechanical bench terraces are series of earth mounds (Photo 3) used as soil conservation techniques for controlling soil erosion and maintain fertility at field and landscape levels in semi-arid areas of Tunisia. Mechanised benches are established to (i) reduce runoff or its velocity in order to minimize soil erosion, (ii) conserve soil moisture and fertility and facilitate modern cropping operations i.e. mechanization, irrigation and transportation on sloping land, and (iii) promote intensive land use and permanent agriculture on slopes and reduce shifting cultivation. They are used to conserve soils in field allocated for different land uses (cereal crops, pasturelands and tree crops). In some cases, the earth mounds are consolidated with some plant species such as *Acacia cyanophilla, Opuntia inermis, Artiplex halimus, Medicago arborea,* etc.

Photo 3. Mechanical bench terraces in Zaghouan. Serie of bench terraces for protecting cereal field (Left). Row unit of terrace bench in olive tree plantation. Olive trees are planted in between rows of terrace benches. (Photo credit: Diwediga B. & Fradi F., March 2017).

- **Manual bench terraces**

Similar to mechanised terrace benches, the manual ones are built for the same purpose of soil conservation techniques and control soil erosion and maintain fertility at field level. As their name indicates, they are constructed manually with hoes, shovels, and pickaxes (Photo 4). They also aim at reducing runoff or its velocity in order to minimize soil erosion, storing runoff water and conserving soil moisture and fertility. The size of the earth mounds is small whereas the runoff retention lines/gutters are dug along the contour lines. They are mostly allocated for tree crops (olive tree, almond trees, etc.).

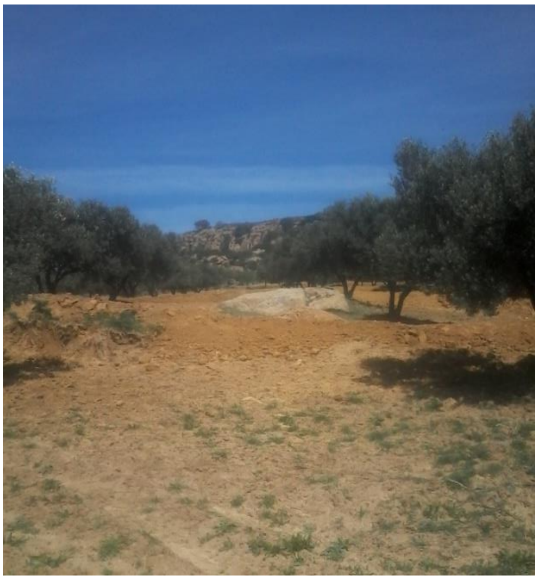



Photo 4. Manual bench terraces dug for erosion control and soil moisture increase in olive tree cropping (Photo credit: Diwediga B. & Fradi F., March 2017).

- **Stone bunds**

"Stone bunds" is an enbankment of stone constructed across the slope following the contour lines (Photo 5). It is a stone wall or line, stabilized in some cases with grasses and fodder plant species. Its main purpose is moisture harvesting and soil erosion control. Establishment is made first by laying out contour lines, digging foundation and placing of stones in a manner to interlock to each other. The purpose is to arrest runoff and enhance soil moisture to increase availability of water to plants. It is also aimed at controlling soil erosion from cultivated fields in such a way that the plants have sufficient soil depth to establish and grow. Maintenance is done every year especially before the rains. The technology is suitable to semi-arid and arid climatic conditions having steep to very steep cultivated lands. It is suitable to major annual cereal crops, perennial crops, fruit trees and cash crops.


Photo 5. Freshly installed stone bunds for protecting olive tree plantation in Zaghouan governorate (Left). Stone bunds combined with tree plantation for bare soil restoration in Medenine (Right). (Photo credit: Diwediga B. & Fradi F., March 2017).

- **Gabion check dams**

“Gabion dams” are commonly used to control gully erosion, prevent waterways enlargement due to lateral erosion, reduce sediment flow, and sometimes for improving water storage and water table recharge. The technology of check dam is a technique consisting of binding different gabion cages filled with small stones together to form a complete flexible gabion unit (Photo 6). To slow down the water flow in the wadi courses and improve its infiltration into deeper soil layers and geologic formations, small check dams are installed on the wadi beds. They are usually positioned in series, with a spacing of 100-500m. The gabion technique has been first introduced in the civil engineering domain. They are largely used since then and found many applications. A gabion is a cage which has a cubic shape filled with stony material of suitable diameter enclosed in metal grating keeping the stones together and stops them from moving under the pressure of water. The gabion is normally the name of the cage only but it is also used frequently for the whole structure itself. The technique of gabion check dam consists in binding different cages together to form a complete gabion unit. In the Southern regions of Tunisia, gabions are used to enable better water infiltration through recharge wells.

Photo 6. Gabion check dams. A freshly installed gabion check dam unit for gully erosion control in Olive plantation in Zaghouan (Left). Gabion unit of a series used to prevent oued enlargement and land degradation in Medenine (Photo: Diwediga B. and Fradi F., March 2017).

3.1.2. Techniques for controlling sand dune mobility

Table 2. SLM practices for controlling sand dune mobility in the pre-Saharan zone of Tunisia

	Techniques	**Socio-Agricultural Ecological Zone (SAEZ)** (as defined in ANNEX 1)	**Aggregated Land Use System (LUS)** (as defined in ANNEX 2)
2.1.	Usage of palm leaves for sand dune stabilisation	SAEZ8	ALUS1; ALUS3
2.2.	Biological stabilisation of sand dunes	SAEZ9	ALUS6

Note: **Socio-agro-ecological zones** (SAEZ1 = Mogods and Kroumerie ; SAEZ2= Nord Est Cap Bon ; SAEZ3 = Dorsale et Tell ; SAEZ4 = Basse steppe ; SAEZ5 = Haute steppe ; SAEZ6 = Chainons atlasiques ; SAEZ7 = Chotts ; SAEZ8 = Dahar et Matmata ; SAEZ9 = Jeffara- El Ouara; SAEZ10 = Grand Erg) and the **aggregated land use systems** (ALUS1 = Irrigated Crops; ALUS2 = Rainfed crops; ALUS3 = Non-irrigated agro-pastoralism; ALUS4 = Irrigated agro-pastoralism; ALUS5 = Pastoralism on bare soils; ALUS6 = Pastoralism on shrub lands; ALUS7 = Natural zones ; ALUS8 = Urban areas; ALUS9 = Parks and natural reserves; ALUS10 = Ramsar sites).

- **Sand dune control using palm leaves**

Sand dune control in the pre-Saharan zones of Southern Tunisia are mostly based on two techniques (Table 2). First, palm leaves are commonly used to construct fences for sand dune mobility (Photo 7A). It consists of building barriers of palm leaves in order to combat wind erosion/sediment transportation. The fences are built perpendicular (if unidirectional winds) or grid based (in case of multi-directional winds) depending on the wind direction.

- **Sand dune control using tree plantation**

The other common practice for sand dune control is the biological stabilisation using tree species (Photo 8 B). This technique consists in planting trees to serve as biological barriers to facilitate the stabilisation of sand dunes and prevent sand deposition. The tree plantation most often is a phase that supports the early stage mechanical stabilisation of sand dunes. In some cases, corrugated cement sheets (or any other available material) can be used to control sand dunes, especially for enclosed areas.

Photo 7. Sand dune control using Palm leave fences (A) and tree species plantation post mechanical stabilisation (B). (Photo: Diwediga B. and Fradi F., March 2017).

3.1.3. Techniques for rangelands management and improvement

Table 3. common techniques for rangeland improvement in the south-eastern Tunisia

	Techniques	**Socio-Agricultural Ecological Zone (SAEZ)** (as defined in ANNEX 1)	**Aggregated Land Use System (LUS)** (as defined in ANNEX 2)
3.1.	Rangeland fallow cropping	SAEZ9	ALUS6
3.2.	Area enclosure	SAEZ8	ALUS6

Note: **Socio-agro-ecological zones** (SAEZ1 = Mogods and Kroumerie ; SAEZ2= Nord Est Cap Bon ; SAEZ3 = Dorsale et Tell ; SAEZ4 = Basse steppe ; SAEZ5 = Haute steppe ; SAEZ6 = Chainons atlasiques ; SAEZ7 = Chotts ; SAEZ8 = Dahar et Matmata ; SAEZ9 = Jeffara- El Ouara; SAEZ10 = Grand Erg) and the **aggregated land use systems** (ALUS1 = Irrigated Crops; ALUS2 = Rainfed crops; ALUS3 = Non-irrigated agro-pastoralism; ALUS4 = Irrigated agro-pastoralism; ALUS5 = Pastoralism on bare soils; ALUS6 = Pastoralism on shrub lands; ALUS7 = Natural zones ; ALUS8 = Urban areas; ALUS9 = Parks and natural reserves; ALUS10 = Ramsar sites).

- **Rangeland resting**

The rangeland fallow cropping is a technique also known as rangeland resting. It is used for rangeland improvement when the degradation reaches a reversible level in the arid environment of Tunisia (Table 3). This technique is based on the principle of leaving the rangeland protected (by excluding grazing during 2-3 years) to allow the plant cover to recover (Photo 8A). It can be assisted by other techniques (tree plantation, area enclosure, forage cropping, biological stabilisation of sand dunes, etc.) to quickly sustain recovery of the rangelands. More details about the technology can be found in the WOCAT SLM database.

- **Area enclosure**

Like rangeland fallow cropping, area enclosure consists in planting trees to serve as protection and reforestation of degraded arid lands. It is commonly developed in the central and southern Tunisia with tree species such as *Acacia tortilis* subsp. *raddiana*. The area enclosure can be assisted by other techniques such as stabilisation of sand dunes using cement concrete, as described in the sub-section above (Photo 8 B). The technical information on the technology can be found in the WOCAT database.

Photo 8. Area enclosure for rangeland resting in the Southern pre-Sahara regions of Tunisia (Left). In some cases, the area is enclosed with wire fences (Right). (Photo credit: Diwediga B. & Fradi F., March 2017)

3.1.4. Techniques targeting specifically water harvesting

In the Table 4 below, various techniques are adopted to collect water for different purposes, including animal consumption, crop irrigation, and forage production.

Table 4. Common techniques targeting water harvesting

	Techniques	**Socio-Agricultural Ecological Zone (SAEZ)** (as defined in ANNEX 1)	**Aggregated Land Use System (LUS)** (as defined in ANNEX 2)
4.1.	Hill reservoirs (lakes and dams)	SAEZ2; SEAZ3; SAEZ5	ALUS1
4.2.	Cisterns	SAEZ8; SAEZ9	ALUS3
4.3.	Wells in desert	SAEZ8	ALUS5
4.4.	Oasis in desert	SAEZ8; SAEZ9	ALUS3
4.5.	Artesian well	SAEZ8	ALUS4
4.6.	Recharge wells	SAEZ9	ALUS1

Note: **Socio-agro-ecological zones** (SAEZ1 = Mogods and Kroumerie ; SAEZ2= Nord Est Cap Bon ; SAEZ3 = Dorsale et Tell ; SAEZ4 = Basse steppe ; SAEZ5 = Haute steppe ; SAEZ6 = Chainons atlasiques ; SAEZ7 = Chotts ; SAEZ8 = Dahar et Matmata ; SAEZ9 = Jeffara- El Ouara; SAEZ10 = Grand Erg) and the **aggregated land use systems** (ALUS1 = Irrigated Crops; ALUS2 = Rainfed crops; ALUS3 = Non-irrigated agro-pastoralism; ALUS4 = Irrigated agro-pastoralism; ALUS5 = Pastoralism on bare soils; ALUS6 = Pastoralism on shrub lands; ALUS7 = Natural zones ; ALUS8 = Urban areas; ALUS9 = Parks and natural reserves; ALUS10 = Ramsar sites).

- **Hill reservoirs (lakes and dams)**

Hill lakes and dams (Photo 9) are specific hydraulic works, respectively of small and medium size, built on secondary waterways in the upstream areas of large watersheds. They are earth-compacted embankments with a lateral outflow channel. Hill lakes and reservoirs are built for soil and water conservation, infrastructures protection in downstream, and local development.

Since 1990s, Tunisia lunched an ambitious national programme for the construction of these hydraulic works across the all semi-arid areas of the country.

Photo 9. Hill reservoirs used for irrigation of cereal crops in the surrounding lands. The reservoirs sides are often consolidated by tree plantation. (Photo: Diwediga B. and Fradi F., March 2017)

- **Cisterns**

Cisterns are reservoirs (photo 10) used for storing rainfall and runoff water for multiple purposes: drinking, animal watering and supplemental irrigation. It consists in digging a pit of up to 100 m^3 and constructing with cement and concrete to harvest and stock runoff water. Cisterns were traditionally used to provide drinking water. In the cistern system, runoff water is collected and stored in stone-faced underground cisterns, of various sizes, called *majel* (private reservoirs) and *fesquia* (communal reservoirs). Basically, a cistern is a hole dug in the ground and lined with a gypsum or concrete coating, in order to avoid vertical and lateral infiltration. Each unit consists of three main parts: the impluvium, the sediment settlement basin, and the storage reservoir. It is estimated that a tank with a capacity of 35 m^3 can meet the annual water needs of a family and its livestock. In flat areas, where it is possible also to exploit floods via a diversion dyke, one also finds artificially paved runoff areas. A small basin before the entrance of the cistern allows the sedimentation of runoff loads. This improves the stored water quality and reduces maintenance costs. Big cisterns have, in addition to the storage compartment, a pumping reservoir from which water is drawn.

Photo 10. A cistern systems for water supply to livestock in the Dahar-Matmata plateau (Photo credit: Diwediga B. & Fradi F., March 2017)

- **Recharge wells**

A recharge well comprises a drilled hole, up to 30-40 m deep that reaches the water table, and a surrounding filter used to allow the direct injection of floodwater into the aquifer. (Photo 11) The main worldwide used methods to enhance groundwater replenishment are through recharge basins or recharge wells. Recharge wells are used in combination with gabion check dams to enhance the infiltration of floodwater into the aquifer. Water is retained by the gabion check dam and it flows through the recharge well allowing accelerated percolation into the deep groundwater aquifers. The recharged aquifers are pumped for irrigated farms.

Photo 11. Recharge well made up of iron tube enclosed by cement-built and filled by gravels, freshly drilled in a wadi (Left). Iron tube drilled serving as recharge well in a wadi (Photo credit: Diwediga B. & Fradi F., March 2017).

- **Oasis and artesian wells**

Some other common practices promoting the soil and land conservation across the two sites were artesian well (Photo 12 Left), and oasis (Photo 12 Right). Commonly, Oasis are developed around, either natural or artificial water points in the desert. Different irrigated cropping systems can be observed: tree crops (palm date trees, olive trees, etc.), cereals, and market gardening. Artesian well, however, is an underground water harvesting technique for human and animal consumption as well as for irrigation. Water under pressure flows endlessly and spill over a small catchment in the surrounding areas.

Photo 12. Water flow from an artesian well drilled in the Dahar-Matmata (Left). Date palm cropping mixed with cereal cropiing in Oasis (Right). (Photo credit: Diwediga B. & Fradi F., March 2017)

3.1.5. Tree-based techniques for land restoration

Table 5. Tree based sustainable land management practice

	Techniques	**Socio-Agricultural Ecological Zone (SAEZ)** (as defined in ANNEX 1)	**Aggregated Land Use System (LUS)** (as defined in ANNEX 2)
5.1.	Reforestation/tree plantation	SAEZ3, SAEZ8	ALUS7

Note: **Socio-agro-ecological zones** (SAEZ1 = Mogods and Kroumerie ; SAEZ2= Nord Est Cap Bon ; SAEZ3 = Dorsale et Tell ; SAEZ4 = Basse steppe ; SAEZ5 = Haute steppe ; SAEZ6 = Chainons atlasiques ; SAEZ7 = Chotts ; SAEZ8 = Dahar et Matmata ; SAEZ9 = Jeffara- El Ouara; SAEZ10 = Grand Erg) and the **aggregated land use systems** (ALUS1 = Irrigated Crops; ALUS2 = Rainfed crops; ALUS3 = Non-irrigated agro-pastoralism; ALUS4 = Irrigated agro-pastoralism; ALUS5 = Pastoralism on bare soils; ALUS6 = Pastoralism on shrub lands; ALUS7 = Natural zones ; ALUS8 = Urban areas; ALUS9 = Parks and natural reserves; ALUS10 = Ramsar sites).

The most common tree-based SLM practice is tree plantation for afforestation or reforestation purposes (Table 5). This technique consists in planting trees to serve as biological barriers to facilitate the stabilisation of sand dunes and prevent sand deposition. The tree plantation most often is a phase that supports the early stage mechanical stabilisation of sand dunes (Photo 13 Left) or to support forest landscape restoration (Figure 13 Right). The technique of tree plantation for biological stabilisation of mobile sand dunes is operated in three successive steps: (1) Plant nursery is produced by the Forest and Agriculture extension services (CRDA in each governorate) of the affected governorates by sand dune deposistion. Tree nursery concerns mostly the following species: *Acacia (cyanophylla, cyclops, salicina, ligulata, tortilis, horrida), Lycium arabicum, Retama reatam, Rhus tripartitum, Caligonum azel, Prosopis juliflora, Parkinsonia aculeata, Eucalyptus (occidentallis, torquata, astringina), Atriplex halimux, etc.* (2) Plantation starting from the first efficient rainfall periods (October, November). The plantation duration varies between 4 and 7 months depending on climatic conditions. Seedlings are carried to the plantation sites using various transportation means. Plantation wholes are digued manually (if sandy soils) or mechanically (if incrusted soils). The average dimensions of the wholes are of 50 cm x 50 cm x 50 cm while the planting density depends on the wind deposition level. (3) Protection of the plantation is ensured by systematically enclosing the planted areas. Regular watering is provided to young trees to ensure high rates of plantation success. this protection may last a period of 3 to 5 years.


Photo 13. Tree plantation for sand dune control in Medenine (Left) and afforestation purposes in Zaghouan (Right). (Photo by Diwediga B. & Fradi F., March 2017)

3.2. Site-specific and common SLM techniques

The spatial distribution of the mapped SLM per administrative units, are provided in Annex 3. In the Zaghouan governorate, eight (08) different SLM techniques were mapped based on field visits. These are: “manual bench terraces”, “mechanical bench terraces”, “hill lakes”, “hill dams”, “Gabions”, “area enclosure”, “stone bunds”, “semi-circular bunds”. The two socio-agro-ecological zones covered by this site are Nord Est Cap Bon and Dorsale-Tell. These sites were predominantly located in mountains and hills, which are favourable to the development of some techniques of water harvesting (e.g. hill lakes and dam).

In the Medenine governorate, the following SLM are identified and mapped: “Jessours”, “Tabias”, “Gabions”, “recharge wells”, “area enclosure”, “citerns” and “wells”, “artesian well”, “stone bunds”, “palm leave fences”). While the socio-agro-ecological zone (SAEZ) of Dahar-Matmata concentrate mostly the “Jessours”, “citerns” and the “wells” (water points). The SAEZ “Jeffara-Ouara”, a coastal zone with relatively flat terrain conditions, is dominated by “Tabia systems”. This is fundamentally defined by the geomorphological and climatic conditions of the area. The other SLMs are erratically spread in both SAEZ, with low adoption level.

Even though they occur in different contexts, the following SLM options were identified to be similar based on their approaches: “rangeland resting”, “tree plantation”, and “area enclosure”. The technique “Gabions” is also common to both sites, however used for different purposes. In the arid conditions (i.e. Medenine governorate), “Gabions” are built for either runoff splashing runoff water towards crop fields or for storing water to aliment recharge wells through infiltration. That is why the “recharge wells” are always associated with “check dams”. In the semi-arid to sub-humid conditions (e.g. Zaghouan governorate), “Gabions” are mostly built for controlling gully erosion in the landscapes.

In terms of SLM options-by-context OxC diversity, in total, 40 SLM OxC data (See Annex 3) were mapped and documented in the database. They belong to19 SLM techniques distributed into 5 technological groups (Anne3 1). They are spread in 5 SAEZs and 7 ALUS all over the two sites. In Zaghouan site, the following SAEZs and ALUS were mapped: SAEZ2 with 3 ALUS (ALUS1, ALUS2, and ALUS3); SAEZ3 with 3 ALUS (ALUS1, ALUS2, ALUS7), SEAZ5 with 1 ALUS (ALUS1), SAEZ8 with 6 ALUS (ALUS1, ALUS2, ALUS3, ALUS4, ALUS5, ALUS7), and SAEZ9 with 6 ALUS (ALUS1, ALUS2, ALUS3, ALUS5, ALUS6, ALUS7).

3.3. Existing SLM technologies not mapped

From the overview of the SLM approaches available for Tunisia, retrievable from the WOCAT database and the LADA report, some SLM OxC Excel form were filled but not mapped (i.e. no ESRI Shapefile were produced) because of the difficulty to geolocate them. These are mainly: “irrigation with salted water”, “Meskats”, “Mgouds”, “Minimum tillage”, “Replanting of local forage species”, “Plantation of forage species”. Their detailed mapping could not be achieved, despite some relevant information exist on these SLM practices. The list of SLM provided in this report is only based on the available literature and field based information. Many other SLM techniques may exist across the whole country, and may be of interest for further investigation.

3.4. Uploaded data in the WebGIS platform

Following the guidelines from the WebGIS installation guide, the SLM shapefiles were uploaded into the MEL database and visualised in the WebGIS. Even though it was to populate the WebGIS system being developed, the purpose was to offer an overview of the final view of the SLM data in the platform. The screenshots in Figure 3 give an overview of WebGIS user interface showing the uploaded shapefiles of SLM practices (in green features) at the zoom extent (Figure 3A) and zoomed in to a specific site (Figure 3B).

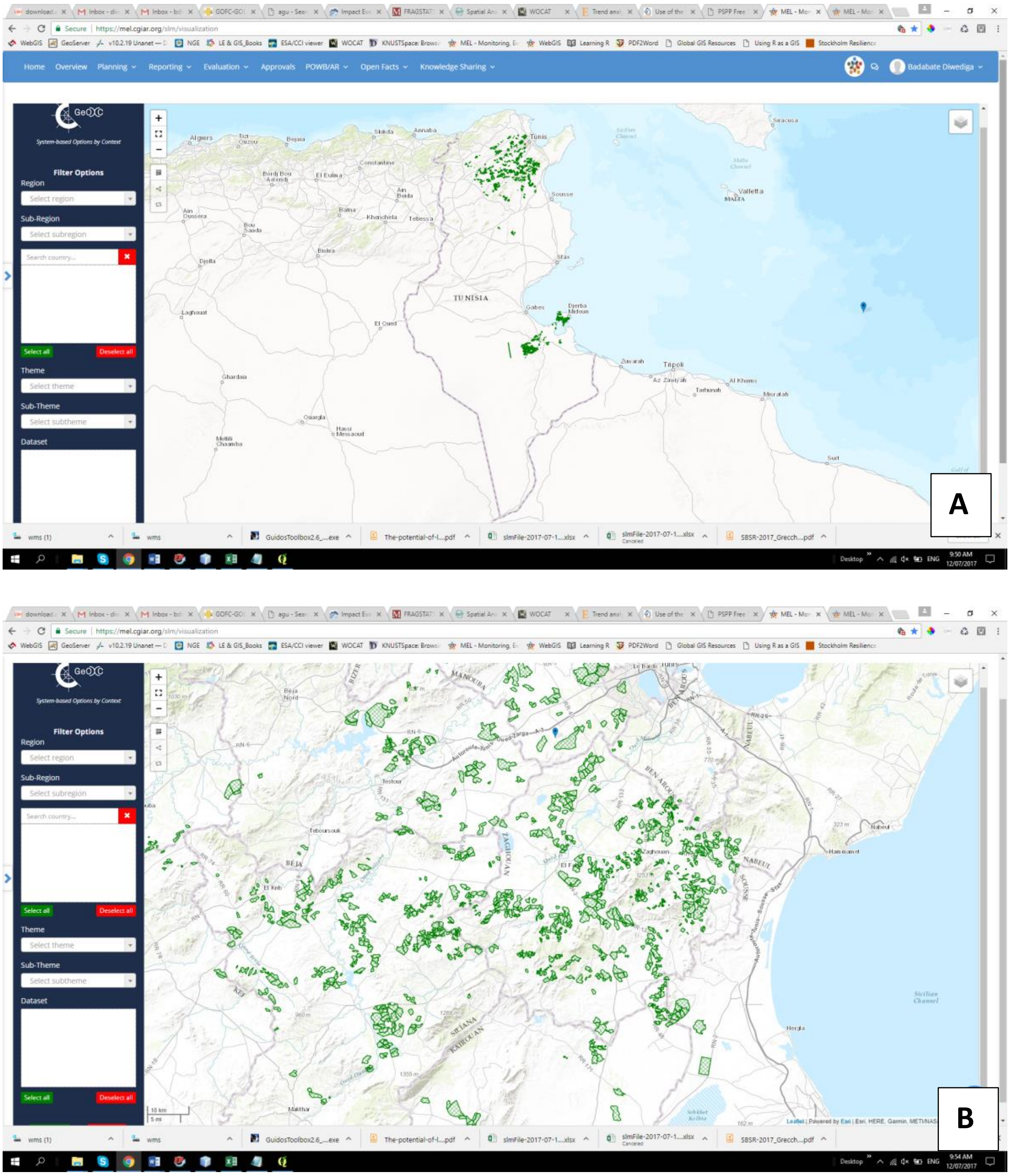


Figure 5. Screenshots of the WebGIS platform showing some SLM technologies mapped (green features) for the two study sites (A). Zoom in to the Zaghouan site in the Northern part of Tunisia (B).

4. Insights to the weaknesses, constraints to the SLM mapping and Learned lessons

Some challenges were faced during the mapping of SLM techniques. First, the lack of SLM mapping standard (basic mapping criteria). Only visited sites/cases (with their exact geographical locations) as well as their exact extent were easily mapped. In addition, extrapolation was made for easily identifiable SLM based on high resolution satellite images. However, no possibility for identifying SLM practices for non-visited sites. The database is therefore not holistic in a spatially-explicit consideration. A second level of limitation is related to the unavailability of data/information for filling in the standardised OxC SLM form and for generating full attributes (metadata) of the mapped SLM technologies. A third limitation level refers to the extent/effect radius of the SLM practices. Even though some techniques (e.g. check dams, hill lakes and dams, and wells) are mapped based on their specific locations, the effects of the purposes expand far beyond their site. For instance, a hill reservoir is mapped based on the extent of the visible water surface and the dam infrastructure. However, the water from this reservoir is used for irrigation within a radius of 500 m. In addition, the impacts of this reservoir is beyond this perceived effects as it cools the weather in the local environment, and can serve as beverage points for livestock moving beyond the effect radius. One can talk about the potential recharge of the groundwater table with positive effects in a relatively large scale. Similar argumentation can hold for wells and gabion check dams. On this basis, the real effects (in terms of spatial coverage and intensity) are still under-evaluated as standardised evaluation and mapping approaches are still lacking. A fourth limitation/challenge was mostly related to the inconsistencies of information across literature. Even though LADA project followed the reporting format of WOCAT frame, the two databases exhibited different attributes on the same SLM technologies.

For instance, “rainfed cereal crops”, “irrigated cereal crops”,“rainfed tree cropping” and “irrigated tree cropping”, are categorised under a same ALUS common to both sites. However, the adopted SLM technologies to ensure impact outcomes on productivity and long term resource preservation, are different and guided by not only the climatic-edaphic factors but also socio-economic and other biophysical settings. Though both sites offer mountainous landscapes, hill lakes and dams are encouraged and largely adopted in Zaghouan with sub-humid to semi-arid conditions where rainwater could easily fill the reservoirs. However, in the southern parts with lower rainfall (arid to semi-arid conditions), such infrastructures could be less advantageous in terms of cost/benefice analysis, as the erratic rainfall could not help in achieving the purposes of such investments. While Jessour and Tabias techniques are well adopted in the southern areas, bench terraces are commonly preferred in Zaghouan. The nature of the soils, landscape structure and climatic regime is the underlying selection factors. Although the contexts are different, there is a commonality in the adoption of the SLM technology to counteract the land degradation process and promote the sustainable use and management of the land resources in both sites. This reveals that “similar challenges appeal for similar solutions” principle. For instance, soil erosion is a common phenomenon nationwide. Even though different contexts exist across the country, similar technologies aim at preventing or reducing, even reversing the degradation processes are encountered. This most common example is the “Gabion check Dams” developed for abating gully erosion. Restoration efforts are also commonly promoted through tree plantation efforts, area enclosure, rangeland resting, and stone bunds development, etc. Even though the overall purpose of the practices is the land degradation mitigation and the improvement of land productivity, desertification process can be enhanced in some cases due to inappropriate practices (use of heavy machinery on fragile lands, exposure of soil surface to wind erosion, etc.). for instance, some practices expose land surface to high evaporation, heat stress on the soil microbiology and increase soil vulnerability to wind erosion. Some efforts should be also done to encourage SLM maintenance, as some visited sites were purely abandoned after huge investments.

5. Conclusion and outlook

Soil and water conservation measures have emerged as a necessity to mainly land users to ensure optimal conservation of natural resources for more productivity. The main goal of this work was to map sustainable land management practices based on the inventory from literature, field based data, and remotely sensed information. To fight degradation that can significantly reduce the soils capacity to produce food and sustain rural livelihoods, multiple practices are often observed throughout landscapes across climatic zones. Many technologies exist in the context of Tunisia, showing the diversity of initiatives to combat land degradation and ensure sustainable lands. This diversity emerges from the synergies from land users, researchers, policy-makers and donor agencies, in order to improve land management, conservation and restoration in arid areas of Tunisia. Each specific context revealed specific SLM practices, even though there exist some similarities. Some practices are very common, and widespread whereas others are very locally applied. Furthermore, there are practices that combine multiples techniques to optimise the efficiency of the conservation purpose. Since this work could not offer a holistic inventory and mapping of the SLM practices in Tunisia, further extensive as and intensive works are desirable to provide a full and more consolidated database that could be more explicit on the context-dependent adoption of SLMs practices. As it is currently difficult to fetch relevant information on SLM practices, it will be valuable if more collaborative efforts are encouraged among national and local stakeholders to document and develop constantly updated database on SLM practices. This information system could easily facilitate access to data and guide some targeted interventions, if needed, for improving the SLM towards achieving land degradation neutrality. Scientific researches are also encouraged towards the assessment of SLM adoption in terms of socio-economical, ecological, hydrological, etc. This impact assessment might guide institutional framework and large-scale adoption of the best practices. Finally, there is a necessity to develop some harmonised standard criteria for mapping SLM (scales, standard measurement units, reporting standards, etc.) at site and landscape levels in order to facilitate comparison of SLM efficiency, upscaling and documentation worldwide. This will facilitate standardised database for the online data portal and the decision support tool (GeOC) to be exhibited as a valuable tool for disseminate knowledge on SLM and supporting policy for better future. As the local knowledge and adoption level are relatively high (based on field observations), it will be desirable and important to expand understanding of the SLM adoption and its real impacts on the ESS and livelihoods at different scales. This first angle (the impact assessment of effective SLM adoption) could be enhanced by the cost-benefit analysis (profitability) for SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of the potential scaling out of more profitable and context-specific technologies. Systematic spatial analysis and time series development of the SLM adoption and categorisation will supplement the impact assessment and its historical change that would be important for reorienting and adapting strategies to the newly evolved conditions. Further considerations can be expanded to the mapping of off-site impacts of some SLM to measure the impact area of their implementation.

6. Acknowledgements

This work is part of the project "*Impact Evaluation of the Sustainable Land Management Practices for achieving Land Degradation Neutrality in Tunisia*" supported by GIZ. We are grateful to all partners of the project. Thanks to Dr. Taoufik Hermassi, Dr. Mahomed Ouessar, Mr Zerrima, K. Karaoud, Boulfagha Farouk, Drivers, National institutions (CES Zaghouan and IRA Medenine) for all facilities. Special thanks to all rural communities for providing valuable information during our visits.

7. References

Anonymous, 2012. Profil environnemental de la Tunisie. European Union, p. 182.

DGACTA, 2008. Rapport de préparation d'une carte LUS nationale: Version préliminaire Réalisation d'une carte d'utilisation des terres à l'échelle 1/500 000 en se basant sur des données nationales disponibles et en suivant les directives LADA pour la starification et la cartographie LUS. In: Ministere de L'agriculture et des Ressources Hydauliques (Ed.). Direction Generale de L'amenagement des Terres Agricoles, Tunisia, p. 76 pp.

DGACTA, IRD, 1996. Annuaire Hydrologique des lacs collinaires 1994-1995. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 176.

DGACTA, IRD, 1997a. Annuaire Hydrologique des lacs collinaires 1995-1996. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 236.

DGACTA, IRD, 1997b. Annuaire Hydrologique des lacs collinaires 1996-1997. Reseau Pilote de Surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 256.

DGACTA, IRD, 1999. Annuaire Hydrologique des lacs collinaires 1997-1998. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 266.

DGACTA, IRD, 2001. Annuaire Hydrologique des lacs collinaires 1999-2000. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 258.

DGACTA, IRD, 2002. Annuaire Hydrologique des lacs collinaires 2000-2001. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 194.

DGACTA, IRD, 2007. Annuaire Hydrologique des lacs collinaires 2002-2003. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 252.

DGACTA, IRD, 2008a. Annuaire Hydrologique des lacs collinaires 2003-2004. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD: 216., Tunis, Tunisia, p. 212.

DGACTA, IRD, 2008b. Annuaire Hydrologique des lacs collinaires 2005-2006. Reseau pilote de surveillance hydrologique. Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 216.

DGACTA, IRD, 2009. Annuaire Hydrologique des lacs collinaires 2004-2005. Reseau pilote de surveillance hydrologique. . Ministere de l'Agriculture, DGACTA and IRD, Tunis, Tunisia, p. 190.

Feeney, M.E., Rajabifard, A., Williamson, I., 2001. Spatial Data Infrastructure Frameworks to Support Decision-Making for Sustainable Development. . Cartagena, Colombia, s.n.

MEAT-Tunisie, 2007. Elaboration d'une étude sur l'état de désertification pour une gestion durable des ressources naturelles.

Schwilch, G., Bestelmeyer, B., Bunning, S., Critchley, W., Herrick, J., Kellner, K., Liniger, H.P., Nachtergaele, F., Ritsema, C.J., Schuster, B., Tabo, R., van Lynden, G., Winslow, M., 2011. Experiences in monitoring and assessment of sustainable land management. Land Degradation & Development 22, 214-225.

Taamallah, H., Ouled Belgacem, A., Nagaz, K., Ouchi, H., Lakhdhar, H., 2010. Gestion durable des terres en Tunisie. Bonnes pratiques agricoles. Direction Generale de l Amenagement et Conservation des Terres Agricoles (DGACTA), Tunis, Tunisie, p. 116.

List of Annexes

Annex 1. List of Socio-agricultural ecological zones (SAEZ) (

Name of SAEZ	CODE of SAEZ	Key characterization	Reference
Mogods and Kroumerie	**SAEZ1**	**Area**: 319 518 ha **Subdivisions**: none **Climate**: humid; **Vegetation/Tree density**: Forests/high **Land use**: important silvo-pastoral potential **Relief**: Hills and mountains **Governorates**: Beja; Jendouba	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Nord Est Cap Bon	**SAEZ2**	**Area**: 802 395 ha **Subdivisions**: none **Climate**: Humid, sub-humid, semi-arid **Vegetation/Tree density**: Forest/medium **Land use**: Tree and cereal crops **Relief**: plains, hills (^200 m), large valleys, domes (^637 m) **Governorates**: Bizerte, Ariana, Beja, Ben Arous, Nabeul, Zaghouan	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Dorsale et Tell	**SAEZ3**	**Area**: 2 365 584 ha **Climate**: Sub-humid to semi-arid (Pmm = 500 – 900 mm/yr) **Vegetation/Tree density**: Forests/ Low (on top hills) **Land use**: Tree and cereal crops **Relief**: hills (>200 m) and mountains (up to 1300 m), vast plains **Governorates**: Jendouba, Beja, Kef, Bizerte, Kairouan, Siliana, Sousse, Kasserine	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Basse steppe	**SAEZ4**	**Area**: 1 866 494 ha **Sub-divisions**: Sidi Mhaddeb; Sousse sahel, Sfax sahel, Basse steppe **Climate**: Humid to subhumid **Vegetation/Tree density**: **Land use**: tree crops, cereal crops, rangelands **Relief** : Plateaus, plains, domes	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007

		Governorates: Sfax, Gabes, Mhadia, Sousse, Sidi BouZid, Kairouan, Monastir	
Haute steppe	**SAEZ5**	**Area**: 1 243 012 ha **Subdivisions :** Hautes steppes agricoles ; Hautes steppes alfatières **Climate**: Semi-arid **Vegetation/Tree density**: Shrubs & herbaceous/Low **Land use**: tree crops, cereal crops **Relief**: plains, Plateaus (700 m), Mountains **Governorates**: Kasserine, Siliana, Kairouan, Sidi BouZid, Sfax, Gafsa	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Chainons atlassiques	**SAEZ6**	**Area**: 698 554 ha **Subdivisions:** none **Climate**: Arid **Vegetation/Tree density**: Sparse shrubs/ Low **Land use**: agriculture **Relief**: Mountains (400 – 600 m) **Governorates**: Gafsa, Sidi Bouzid, Kebili, Sfax, Gabes	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Chotts	**SAEZ7**	**Area**: 1 964 074 ha **Sub-divisions:** none **Climate**: arid **Vegetation/Tree density**: sparse steppe, psammophile **Land use**: tree and cereal crops in oasis, Rangelands **Relief**: Plains **Governorates**: Kebili, Tozeur, Gafsa, Gabes	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Dahar et Matmata	**SAEZ8**	**Area**: 1 879 603 ha **Sub-divisions:** none **Climate**: arid **Vegetation/Tree density**: Mountain alfa and forest patches, sparse to dense low vegetation **Land use**: rare crops, rare rangelands **Relief**: hills, mountains **Governorates**: Gabes, Kebeli, Medenine, Tatouine	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007

Jeffara- El Ouara	**SAEZ9**	**Area**: 1 591 197 ha **Sub-divisions: El Ouara, Jeffara** **Climate**: arid (Saharan Mediterranean) **Vegetation/Tree density**: halophile steppe **Land use**: Rangelands, tree crops, cereal crops **Relief**: plains **Governorates**: Medenine, Tatouine, Gabes	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007
Grand Erg	**SAEZ10**	**Area**: 2 761 748 ha **Subdivisions:** None **Climate**: arid **Vegetation/Tree density**: sparse vegetation **Land use**: rare rangelands, parks and reserves **Relief**: sand dunes **Governorates**: Kebili, Gabes, Tataouine	CNEA/Elaboration d'une étude sur l'état de désertification pour une gestion durable des RN/Avril2007

Annex 2. List of Aggregated Land Use Systems (ALUS). Sources: DGACTA- Tunisia (2008)

Aggregated LUS (ALUS)	CODE for ALUS	Primary LUS in Tunisian LADA classification (multiple categories be separated by semicolon)	Code for primary LUS
Irrigated Crops	**ALUS1**	1. Citrus trees	Cr_irrig_citrus
		2. Tree crops	Cr_irrig_tree
		3. Garden market crops	Cr_irrig_gard
		4. Palm trees	Cr_irrig_palm
		5. Great crops	Cr_irrig_great
Rainfed crops	**ALUS2**	1. Citrus trees	Cr_rain_citrus
		2. Garden market crops	Cr_rain_gard
		3. Great crops	Cr_rain_great
		4. Olive trees	Cr_rain_oliv
		5. Palm trees	Cr_rain_palm
		6. Orchards	Cr_rain_orch
		7. Vineyard	Cr_rain_vine
Non-irrigated agro-pastoralism	**ALUS3**	1. Intensive breeding	No_irrig_agro_past_int
		2. Semi-intensive breeding	No_irrig_agro_past_semi
		3. Extensive breeding	No_irrig_agro_past_ext
Irrigated agro-pastoralism	**ALUS4**	1. Intensive breeding	Irrig_agro_past_int
		2. Semi-intensive breeding	Irrig_agro_past_semi
		3. Extensive breeding	Irrig_agro_past_ext
Pastoralism on bare soils	**ALUS5**	1. Extensive	Past_bare_ext
		2. Semi-intensive	Past_bare_semi
		3. Intensive	Past_bare_int
Pastoralism on shrub lands	**ALUS6**	1. Extensive	Past_sh_ext
		2. Semi-intensive	Past_sh_semi
		3. Intensive	Past_sh_int
Natural zones	**ALUS7**	1. Bare soils	Bare_ar
		2. Water	Water
		3. Forests	Forest

		4. Shrubs- Mosaic of sparse shrubs herbaceous	Sh_h_ar
Urban areas	**ALUS8**	Excluded	Urb
Parks and natural reserves	**ALUS9**	Excluded	Protect_1
Ramsar sites	**ALUS10**	Excluded	Protect_2

Annex 3. Overview of the mapping SLM technologies and SLM OxC data

SLM ID	**Technique**	**References**	**Socio-Agricultural Ecological Zone (SAEZ)** (if the SLM is selected, then write the relevant code in ANNEX 1a)	**Land Use System (LUS)** (if the SLM is selected, then write the relevant code in ANNEX 1b)	**Name of documented of the SLM OxC template** (syntax: <technique>_<SAEZ code>_<ALUS code>_<short name of documenter>.xlsm)	**Name of visual file of the SLM OxC** (syntax: <technique>_<SAEZ code>_<ALUS code>_<short name of documenter>.zip; zip file includes: 5 files of GIS shape + a Google Earth image of an example site in jpg + 1-2 field photos in jpg + a technical sketch of the technique in jpg)
1. Techniques targeting specifically water and soil conservation						
1.8.	Jessours	Tunisian LADA Report 2010; WOCAT Database 2017	SAEZ8	ALUS2	Jessours_SAEZ8_ALUS2_BD.xlsm	Jessours_SAEZ8_ALUS2_BD.zip
			ZAEZ9	ALUS2	Jessours_SAEZ9_ALUS2_BD.xlsm	Jessours_SAEZ9_ALUS2_BD.zip
1.9.	Tabia	Tunisian LADA Report 2010; WOCAT Database 2017	SAEZ8	ALUS2	Tabias_SAEZ8_ALUS2_BD.xlsm	Tabias_SAEZ8_ALUS2_BD.zip
			SAEZ8	ALUS5	Tabias_SAEZ8_ALUS5_BD.xlsm	Tabias_SAEZ8_ALUS5_BD.zip
			SAEZ9	ALUS2	Tabias_SAEZ9_ALUS2_BD.xlsm	Tabias_SAEZ9_ALUS2_BD.zip
			SAEZ9	ALUS5	Tabias_SAEZ9_ALUS5_BD.xlsm	Tabias_SAEZ9_ALUS5_BD.zip

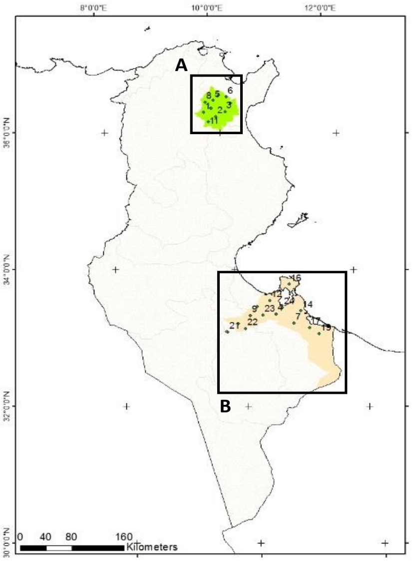
1.10.	Mechanical bench terraces	Roose E. (2002) Roose E. (2005)	SAEZ2 SAEZ2 SAEZ2 SAEZ3 SAEZ3	ALUS1 ALUS2 ALUS3 ALUS1 ALUS2	Mechanised_terraces_SAEZ2_ALUS1_BD.xlsm Mechanised_terraces_SAEZ2_ALUS2_BD.xlsm Mechanised_terraces_SAEZ2_ALUS3_BD.xlsm Mechanised_terraces_SAEZ3_ALUS1_BD.xlsm Mechanised_terraces_SAEZ3_ALUS2_BD.xlsm	Mechanised_terraces_SAEZ2_ALUS1_BD.zip Mechanised_terraces_SAEZ2_ALUS2_BD.zip Mechanised_terraces_SAEZ2_ALUS3_BD.zip Mechanised_terraces_SAEZ3_ALUS1_BD.zip Mechanised_terraces_SAEZ3_ALUS2_BD.zip
1.11.	Manual bench terraces	Tunisian LADA Report 2010	SAEZ2	ALUS2	Manual_terraces_SAEZ2_ALUS2_BD.xlsm	Manual_terraces_SAEZ2_ALUS2_BD.zip
1.12.	Stone bund terraces	Tunisian LADA Report 2010	SAEZ2 SAEZ9	ALUS2 ALUS7	Stone_bunds_SAEZ2_ALUS2_BD.xlsm Stone_bunds_SAEZ9_ALUS7_BD.xlsm	Stone_bunds_SAEZ2_ALUS2_BD.zip Stone_bunds_SAEZ9_ALUS7_BD.zip
1.13.	Gabion check dams	Tunisian LADA Report 2010 WOCAT Database 2017	SAEZ8 SAEZ9	ALUS1 ALUS1	Gabions_SAEZ8_ALUS1_BD.xlsm Gabions_SAEZ9_ALUS1_BD.xlsm	Gabions_SAEZ8_ALUS1_BD.zip Gabions_SAEZ9_ALUS1_BD.zip

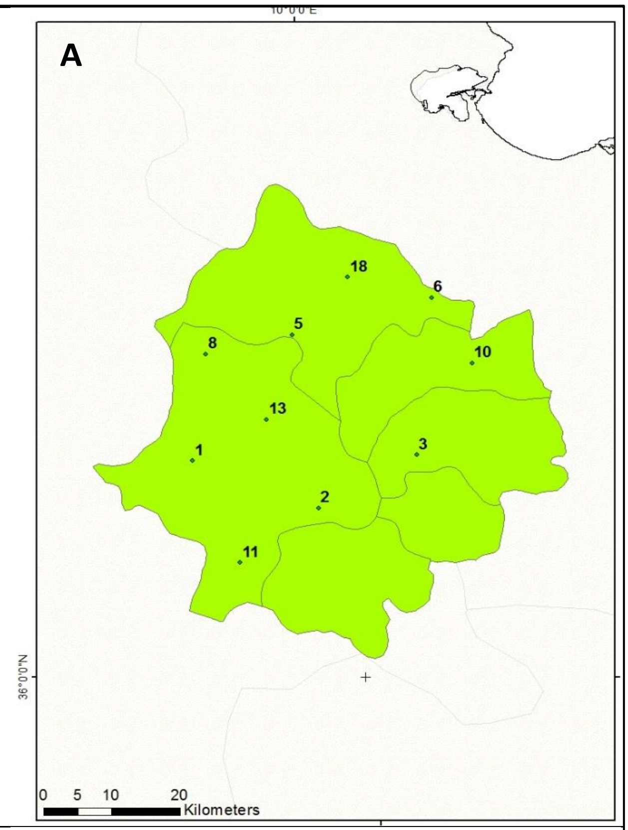
			SAEZ2 SAEZ3	ALUS2 ALUS2	Gabions_SAEZ2_ALUS2_BD.xlsm Gabions_SAEZ3_ALUS2_BD.xlsm	Gabions_SAEZ2_ALUS2_BD.zip Gabions_SAEZ3_ALUS2_BD.zip
1.14.	Individual micro-catchment		SAEZ2	ALUS2	Micro-catchment_SAEZ2_ALUS2_BD.xlsm	micro-catchment_SAEZ2xALUS2_BD.zip
2. Techniques for controlling sand dune mobility						
2.3.	Usage of palm leaves for sand dune stabilisation	Tunisian LADA Report 2010; WOCAT Database 2017	SAEZ8 SAEZ8 SAEZ9 SAEZ9	ALUS1 ALUS3 ALUS1 ALUS3	Palm_fences_SAEZ8_ALUS1_BD.xlsm Palm_fences_SAEZ8_ALUS3_BD.xlsm Palm_fences_SAEZ9_ALUS1_BD.xlsm Palm_fences_SAEZ9_ALUS3_BD.xlsm	Palm_fences_SAEZ8_ALUS1_BD.zip Palm_fences_SAEZ8_ALUS3_BD.zip Palm_fences_SAEZ9_ALUS1_BD.zip Palm_fences_SAEZ9_ALUS3_BD.zip
2.4.	Biological stabilisation of sand dunes	Tunisian LADA Report 2010; WOCAT Database 2017	SAEZ9	ALUS6	Biological_fixation_dunes_SAEZ9_ALUS6_BD.xlsm	Biological_fixation_dunes_SAEZ9_ALUS6_BD.zip

3. Techniques for rangelands management and improvement						
3.3.	Rangeland fallow cropping (rangeland resting)	Tunisian LADA Report 2010; WOCAT Database 2017	SAEZ9	ALUS6	Rangeland resting_SAEZ9_ALUS6_BD.xlsm	Rangeland resting_SAEZ9_ALUS6_BD.zip
3.4.	Area enclosure		SAEZ9	ALUS7	Area enclosure_SAEZ9_ALUS7_BD.xlsm	Area enclosure_SAEZ9_ALUS7_BD.zip
4. Techniques targeting specifically water harvesting						
4.7.	Hill dams	Technical reports (DGACTA, 2005)	SAEZ2 SAEZ3	ALUS1 ALUS1	Hill_dam_SAEZ2_ALUS1_BD.xlsm Hill_dam_SAEZ3_ALUS1_BD.xlsm	Hill_dam_SAEZ2_ALUS1_BD.zip Hill_dam_SAEZ3_ALUS1_BD.zip
4.8.	Hill lakes	Technical reports (DGACTA, 2005)	SAEZ2 SAEZ3 SAEZ5	ALUS1 ALUS1 ALUS1	Hill_lake_SAEZ2_ALUS1_BD.xlsm Hill_lake_SAEZ3_ALUS1_BD.xlsm Hill_lake_SAEZ5_ALUS1_BD.xlsm	Hill_lake_SAEZ2_ALUS1_BD.zip Hill_lake_SAEZ3_ALUS1_BD.zip Hill_lake_SAEZ5_ALUS1_BD.zip
4.9.	Cisterns	Tunisian LADA Report 2010	SAEZ8 SAEZ9	ALUS3 ALUS3	Citerns_SAEZ8_ALUS3_BD.xlsm Citerns_SAEZ9_ALUS3_BD.xlsm	Citerns_SAEZ8_ALUS3_BD.zip Citerns_SAEZ9_ALUS3_BD.zip

4.10.	Wells in desert		SAEZ8	ALUS5	Wells in desert_SAEZ8_ALUS5_BD.xlsm	Wells in desert_SAEZ8xALUS5.zip
4.11.	Oasis in desert		SAEZ8 SAEZ9	ALUS3 ALUS3	Oasis_SAEZ8_ALUS3_BD.xlsm Oasis_SAEZ9_ALUS3_BD.xlsm	Oasis_SAEZ8_ALUS3_BD.zip Oasis_SAEZ9_ALUS3_BD.zip
4.12.	Artesian well		SAEZ8	ALUS4	Artesian_well_SAEZ8_ALUS4_BD.xlsm	Artesian_well_SAEZ8_ALUS4_BD.zip
4.13.	Recharge wells	WOCAT database	SAEZ9	ALUS1	Recharge well_SAEZ9xALUS1_BD.xlsm	Recharge well_SAEZ9xALUS1_BD.zip
5. Tree-based techniques						
5.2.	Reforestation/tree plantation		SAEZ3 SAEZ8	ALUS7 ALUS7	Tree_plantation_SAEZ3_ALUS7_BD.xlsm Tree_plantation_SAEZ8_ALUS7_BD.xlsm	Tree_plantation_SAEZ3_ALUS7_BD.zip Tree_plantation_SAEZ8_ALUS7_BD.xlsm

Annex 4. Distribution of the mapped SLM according the visited governorates of Tunisia





Legend

1 = Mechanised bench terraces
2 = Hill dams
3 = Hill lakes
4 = Area enclosure
5 = Area enclosure
6 = Tree plantation
7 = Tree plantation
8 = Gabion check dams
9 = Gabion in the south
10 = Manual bench terraces
11 = Stone bunds
12 = Stone bunds in the South
13 = Individual micro-catchments
14 = Palm leave fences
15 = Jessours
16 = Tabias
17 = Biological stabilistationof sand dunes
18 = Rangeland resting
19 = Rangeland resting
20 = Oasis
21 = Artesian well
22 = Well in desert
23 = Recharge well
24 = Citerns