TECHNICAL IMPLEMENTATION REPORT

Soil erosion evaluation using advanced laboratory measurement methods to support climate-resilient agriculture and food security

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RCMRD CTCN UN Climate Technology Centre & Network

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LIST OF ACRONYMS

AAS	Atomic absorption spectroscopy/ spectrophotometer
ACSAD	Arab center for the studies of arid zones and dry lands
CS-SLM	Climate-smart sustainable land management
CTCN	United Nations Climate Technology Centre and Network
DEM	Digital elevation model
DSM	Digital soil mapping
EO	Earth observation
FAO	Food and Agriculture Organization of the United Nations
GA	Gender action
GEE	Google earth engine
GIS	Geographical information systems
GPS	Global positioning system
KC&D	Knowledge communication and dissemination
M&E	Monitoring and evaluation
NDVI	Normalized difference vegetation index
NRGD	Natural Resources General Directorate of the Ministry of Agriculture and Forests
PSM	Predictive soil modelling
RCMRD	Regional Center for Mapping of Resources for Development
RNS	River Nile State
RUSLE	Revised universal soil erosion equation
SWALIM	Somalia water and land information management
TA	Technical assistance
TWG	Technical working group
UAV	Unmanned aerial vehicle (also known as drone)
USDA	United States Department of Agriculture
VHF	Very high frequency
VLoS	Visual line of sight
VTOL	Vertical take-off and landing
WRB	World Reference Base of soil classification

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1.0 INTRODUCTION

1.1 Background and Context

The increasing frequency of climatic extremes, particularly droughts, high-velocity wind storms, erratic rainfall, and floods has exposed the northern parts of Sudan to both wind and water erosion. Anthropogenic factors, such as inappropriate land use practices and over-exploitation of natural resources have also accelerated the soil erosion rates. This has in turn affected the productivity of the grazing and agricultural lands, rural livelihoods, and food and nutrition security in the country. However, these impacts are still not well-understood due to the complex nexus between climate change and land degradation, and lack of biophysical soil health indicators and a standardized methodological framework for evaluating soil erosion and its effects on crops.

To address the foregoing issues, the Natural Resources General Directorate of the Ministry of Agriculture and Forests (NRGD) in Sudan sought and received Technical Assistance (TA) from the United Nations Climate Technology Centre and Network (CTCN) to evaluate soil erosion and the associated impact on functional soil properties using advanced soil analysis, Earth Observation (EO) and Predictive Soil Modelling (PSM) technologies (e.g., atomic absorption spectroscopy [AAS] and Unmanned Aerial Vehicles [UAVs]) to support climate-resilient agriculture and food security in Sudan. In particular, the NRGD intends to map the spatial patterns of soil erosion risk and functional soil properties (e.g., soil organic carbon, pH and micro-nutrients), quantify the annual soil loss rates, and delineate the priority areas for Climate-Smart and Sustainable Land Management (CS-SLM).

Unfortunately, the NRGD has not had any opportunity to utilize and fully benefit from advanced EO and PSM technologies due to a number of technical, financial and infrastructural challenges. Therefore, to execute this TA, the Regional Centre for Mapping of Resources for Development (RCMRD), an inter-governmental organization with 20 member states in Eastern and Southern Africa, was engaged based on its long-standing and proven expertise and track record of facilitating trainings, conducting natural resource assessments, and generating, applying and disseminating geospatial technologies in Africa. In doing so, RCMRD uses surveying, mapping, remote sensing and GIS technologies. RCMRD has also successfully delivered a CTCN-supported technical assistance in the Kingdom of Eswatini. It is anticipated that the TA will enhance technological capacities by filling information gaps, providing physical and human capacities, and demonstrating the application and supporting the transfer of EO technologies and tools, including the use of UAVs to monitor the human- and climate-induced soil degradation, as well as the impacts on agricultural productivity. This will, ultimately, strengthen soil monitoring systems and enhance agricultural resilience.

2.0 PROJECT IMPLEMENTATION AREA

The TA will be implemented in Al Damar (Ad Damer, Ed Damer) District of the River Nile State (RNS), which lies between Latitudes 17° 11' 9.6" and 18° 6' 46.8" N, and Longitudes 32° 28' 12" and 33° 59' 45.6" E, at an altitude of 1,158 feet (353 m) above sea level (Figure 1). It covers an area of 10,866 km², which is dominated by Aridisols (i.e., dry soils with $CaCO_3$ accumulations), semi-desert vegetation (i.e., scrubs and grasslands) and semi-arid climatic conditions. The mean annual rainfall is about 56 mm, most of which is received between July and September, relative humidity is less than 40 percent, and temperatures are as high as 43°C between April and June, and as low as 14°C in January (El Ghazali et al., 2021). In addition, the shortwave solar radiation is as high as 659 calorie cm^{-2} in May, while the mean maximum wind speed is about 17.6 km^{-hr}. Owing to these extreme climatic conditions, agricultural activities are majorly confined on the banks of the Nile River. In terms of physiography, the landform of Al Damar is characterized by flat to slightly undulating desert plains, rising from 100 to 600 feet above sea level, with wadis, sand dunes, and low ridges and hills appearing in some parts. The population was about 284,148 in 2008 (https://unstats.un.org).

Out of the seven (7) districts in the RNS, Al Damar was selected as the ideal site for implementing the TA by the Technical Working Group (TWG) because it: (i) has been adversely affected by climate change and land degradation processes, particularly, soil erosion by water and wind, which is the focus of this TA; (ii) hosts one of the four (4) government-funded food security projects in the RNS; thus, the data gathered during soil surveys and UAV operation will also be critical in the development of crop suitability maps that will inform the choice of crops to be grown within the food security site; (iii) has baseline data that was collected by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) in 2019; (iv) exhibits high spatial variability of soils; and, (v) is the capital of the RNS; hence, support from the state government is guaranteed.

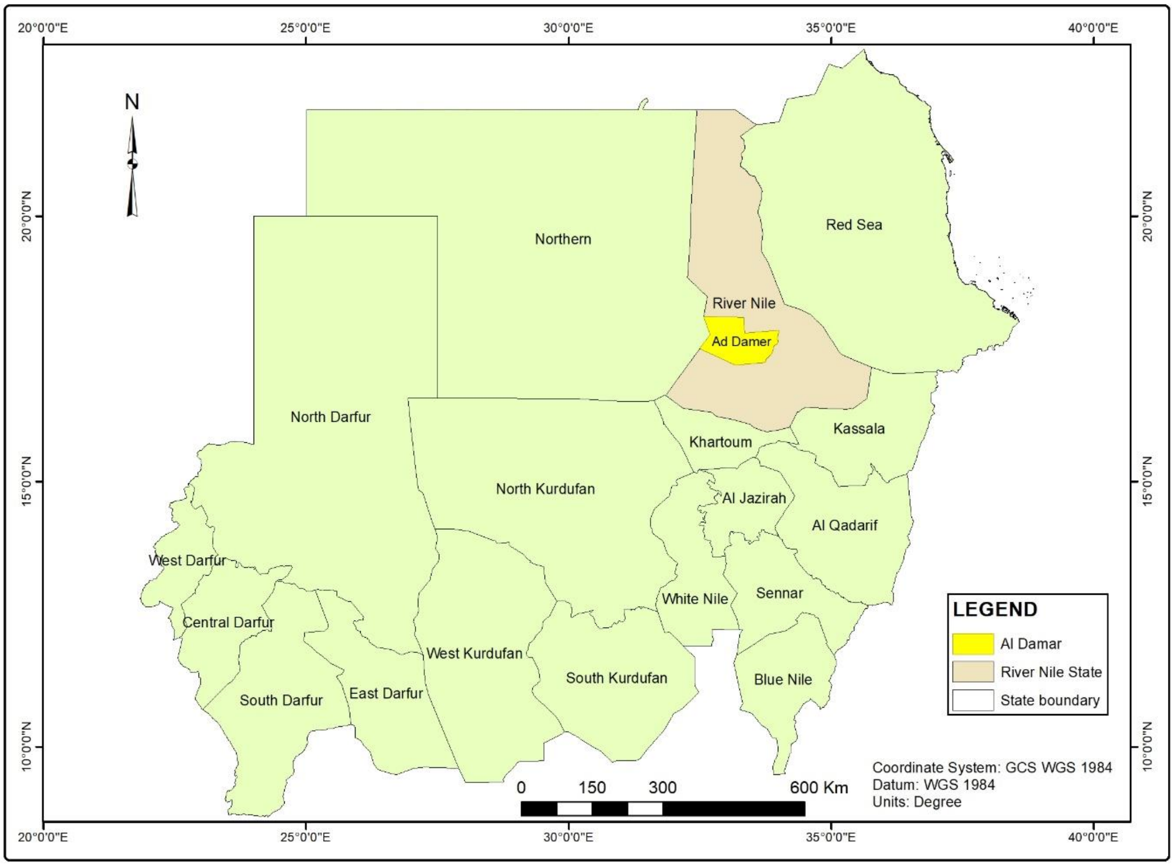

Figure 1: Location of Al Damar District in the River Nile State, Sudan

3.0 MAIN ACTIVITIES AND APPROACHES

3.1 Field Surveys

3.1.1 Soil Survey

Soil survey will entail describing the soil surface and profile characteristics, collecting soil samples for physical and chemical analysis at the laboratory, as well as classifying the soils. Prior to the field campaign, a field survey manual will be developed to provide guidelines for fieldwork preparations, field observations and sample collection. It will describe in detail the field equipment and materials, sampling design (e.g., stratification of the project area), and specifications and requirements for soil sample collection (e.g., number of samples to collect and sampling depth), as well as for sample handling and packaging. This will also serve as a knowledge product that can be used by similar projects in the future to ensure consistency and harmony in soil data collection in Sudan. As such, in developing the field survey manual, reference will also be made to the existing field protocols, previous soil mapping works and literature.

But generally speaking, a variety of equipment and tools will be used to collect soil data in the field, including the Munsell soil colour chart, soil auger (spade, backhoe or shovel), geologist's hammer, large knife, trowel, measuring tape, hand lens, clinometers, plastic sampling bags, labelling tags, thread, plastic bucket, hand-held global positioning system (GPS) receiver (and batteries), jute (gunny) bags, and standard profile and auger description forms (Soil Survey Staff, 1999; FAO-SWALIM, 2007).

Soil samples will be collected at two (2) levels; namely, (i) the whole of Al Damar District and (ii) the food security project site within Al Damar. In Al Damar, direct field observations will be made by soil auger. That is, augering will be performed up to a depth of 30 cm and soil samples taken randomly at representative and well-distributed sites, which reflect the spatial variability in terms of physiography, geology, land use and soil types. Therefore, ancillary geospatial data, including EO satellite imagery and Digital Elevation Model (DEM) will be compiled and overlaid to stratify the landscape into units with similar combinations of relief, soil types, land use and geology for the randomization of sampling sites. Each sampling site will be geo-referenced using a hand-held GPS receiver with a positional accuracy of 5 meters. The samples collected at each site will be thoroughly mixed, bulked into a composite sample weighing about 500g and transported to the Central Soil Laboratory of the NRGD for physical and chemical analysis.

In contrast, at the food security project site within Al Damar, a semi-detailed soil survey will be conducted at a scale of 1:50,000, with more detailed soil auger and profile pit observations. Soil profile descriptions will provide exhaustive information on soil-forming processes and properties relating to site productivity (Kenya Soil Survey Staff, 1987). For observations by soil auger, augering will be performed up to a depth of 120 cm (or to a hindering layer) following a grid pattern, with a spacing of 200 m between auger holes. At each auger hole, general and site information, such as observation ID, date, surveyor's name, coordinates, altitude, landform, lithology, slope gradient, (macro-, meso- and micro-relief, moisture, depth, colour, drainage, texture, structure, consistence, concretions, mottling, surface sealing, crusting, cracking, compaction, presence of salts, rockiness (rock outcrops), stoniness, erosion, vegetation, land use, flooding, root distribution, porosity, biological features (e.g., soil fauna), effective soil depth and human influence will be recorded on a standard auger hole description form (FAO-SWALIM, 2007). The soil auger observations will be examined and characterized following FAO Guidelines (FAO-UNESCO, 1997; FAO, 2006) to delineate the soil mapping units. Thereafter, representative soil profile pits will be sited and dug in the delineated soil mapping units (i.e., 3 profile pits per major mapping unit and 2 for other units). At each profile pit, the diagnostic horizons will be identified, described and sampled for chemical and physical analyses. The information to be recorded on the soil profile description form will be similar to those listed above for the observations by soil auger, with the only addition being the soil profile photographs. Lastly, the soil profiles will be tentatively classified based on incomplete field data using either the World Reference Base (WRB) soil classification system (FAO, 2006) or USDA soil taxonomy system (Soil Survey Staff, 1999). But once the complete field and laboratory data are out, the final soil classification will be made.

3.1.2 UAV/ Drone Survey

The advent of UAVs has pushed the frontiers of spatial data acquisition and environmental monitoring. They are increasingly being used in many fields, including in soil data collection, because of their flexibility during field operations and provision of data with a spatial resolution of less than a meter. In this TA, UAV technology will also be utilized. The ideal UAV for soil mapping will be a fixed-wing drone with Vertical Take-off and Landing (VTOL) capabilities, which can conduct both small- and large-scale surveys designed to cover long distances, with a maximum flight time of above 55 minutes. The drone will also be fitted with a multi-spectral sensor to capture data in the red, green, blue and near infra-red portions of the electromagnetic spectrum. A fixed-wing drone is often more suitable and beneficial for agricultural applications, especially where the area being mapped is large, and the take-off and landing space is not limited. Its endurance and high-cruising speed allows for a greater area of land to be mapped up to 2.6x faster, with an object resolution of cm (or inch) per pixel, and users also benefit from its ability to withstand high winds.

The UAV data will be collected concurrently with the EO satellite and soil data in a pilot area covering 7 km × 7 km (50 km^2) across the food security site in Al Damar. Before the survey, the primary fixed-wing drone will be tested and, as a precautionary measure, a backup drone will also be on standby in case the primary drone develops technical issues. Permission to bring and operate drones in Sudan will also be sought from the Survey Department. To alleviate time wastage due to travel while in the field, the UAV team will put up close to the area where the flight missions will be undertaken. In terms of the timings for data acquisition, the flight missions will be executed between 11 am and 2 pm when the sun is overhead to avoid long shadows, which compromise data quality. Each flight will be within a 1-km geo-fence, or a Visual Line of Sight (VLoS), as prescribed by most civil aviation authorities. This implies that each flight will be able to capture at least 1 km^2. On a good day, three (3) flights can be achieved, which translates to 3 km^2 per day. Therefore, to cover the entire pilot site, approximately 17 working days will be needed for the drone survey. Weekends will be reserved for the UAV pilots to rest, recharge equipment and back up data.

While conducting the flight missions, the UAV team will ensure that the requisite ancillary equipment are available on site to support the coordination, safety, and data acquisition and storage. These include, *inter alia*, radios (VHF and Airband), modem or Wi-Fi connection, external hard disks, pylon marking cones, landing zone, diesel-powered generator to recharge batteries, laptops, remote controller, anemometer, compass, electrical power cables, drone tablet, and a tent to serve as a temporary workstation.

3.2 Soil Sample Preparation and Analysis

All soil samples collected in the field will be transported to the Central Soil Laboratory of the NRGD for analysis. Once the soil samples are received at the laboratory, the information provided on the sample bags will be recorded in a sample register. The samples will then be air-dried to a constant weight in a room free of contaminants, the air-drying of which will minimize biological activity and loss of nutrients. Any rock fragments, small stones, gravel, plant residues and other foreign particles will be removed and the remaining soil passed through 2 mm sieve to obtain representative subsamples. Clods not passing through the sieve will be crushed by a pestle and mortar (van Reeuwijk, 2002). The air-dried fine soil is what will be subjected to laboratory analysis using the AAS and other appropriate equipment, such as the flame photometer and pH meter. Some of the soil physical and chemical parameters that will be analyzed include texture, pH, EC, CEC, ESP, exchangeable cations (Ca, Mg, K and Na), Fe, Zinc, Mn, phosphorus, total nitrogen, organic carbon, and calcium carbonate ($CaCO_3$).

3.3 Soil Erosion Modelling

This activity will provide and execute a detailed, rapid, cost-effective and replicable framework for spatial assessment of land susceptibility to water erosion. The assessment will (i) determine the spatial patterns of soil erosion risk, (ii) quantify the annual soil loss rates, and (iii) delineate the hotspots of soil erosion and priority areas for targeting CS-SLM interventions.

To generate the spatially-distributed soil erosion risk map, the revised universal soil loss equation (RUSLE) model will be used. This model, which was developed in the 1990s, is appropriate and has been widely used by soil conservationists to estimate the long-term average annual loss of soil through rill and sheet erosion because of its simplicity, high estimation accuracy, moderate data demand, compatibility with EO data and GIS tools and ability to estimate soil loss in large spatial domains (Fenta et al., 2020; Wang and Zhao, 2020; Elnashar et al., 2021; Kebede et al., 2021). It integrates the five (5) major factors that affect soil erosion rates in any given landscape as expressed in Eq. (1).

$$A = R \times K \times LS \times C \times P \qquad \text{Eq. (1)}$$

where: A is the estimated mean annual soil loss (tons ha^{-1} yr^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility factor (Mg h MJ^{-1} mm^{-1}), LS is the slope length and steepness factor (unitless), C is the soil cover management factor (unitless) and P is the soil conservation practice factor (unitless). Many methods are available in the literature to calculate these inputs, often using freely available data (Getu et al., 2022).

The requisite geospatial datasets for building the RUSLE model, including rainfall, soil properties (e.g., soil texture and organic matter content) and EO satellite-derived land cover, Normalized Difference Vegetation Index (NDVI) and DEM will be retrieved and processed within the novel Google Earth Engine (GEE) platform. This online platform has a multi-petabyte catalog of geospatial data open for public use, as well as powerful capabilities for computing and analyzing these data in the cloud (Papaiordanidis et al., 2019; Wang et al., 2020; Wang and Zhao, 2020; Elnashar et al., 2021). The use of GEE platform in this TA will allow for rapid development and delivery of digital soil erosion risk maps and automation of the entire soil erosion modelling process.

3.3.1 Application of EO UAV Data in Soil Erosion Modelling

To exploit the utility of UAVs in unravelling soil erosion dynamics, the processed UAV data will be used to generate high-resolution information, such as land cover types, spectral vegetation indices (e.g., NDVI) and LS factor for the 50 km^2 pilot area. These will be ingested into the RUSLE modelling framework in GEE environment to reveal the severity and extent of soil erosion in the pilot area. Subsequently, the soil erosion risk map produced using the EO UAV-derived data and the one created using the EO satellite-derived data will be compared to see whether there are any significant differences in accuracy and details.

3.3.2 Identification of CS-SLM Measures to Mitigate Soil Erosion

Appropriate CS-SLM measures to be targeted at the delineated hotspots of soil erosion and priority areas will be identified and selected in an all-inclusive and participatory manner, involving views and contributions from the key stakeholders to encourage ownership, support and application of the measures. Thereafter, a Strategic Action Plan will be developed, which will highlight the specific soil erosion problem, remedial action(s), responsible stakeholder(s) to implement the remedial action(s), timelines, and the resources required.

3.3.3 Development of Criteria and Indicators to Monitor Soil Erosion

It is anticipated that the delivered soil erosion risk map and estimates will be used as a baseline for future monitoring and reporting on soil erosion dynamics in Al Damar District. Potential monitoring sites will be identified within the hotspots of topsoil loss on the map for repeated measurements of soil erosion using the same techniques and at the same time of the year. This TA will, in consultation with the key stakeholders, develop the criteria and indicators that will be used to measure soil erosion at the monitoring sites. The indicators to measure and observe could vary from topsoil loss (presence of rill or sheet erosion) and increase in the size of the rills (width, length and depth) to soil surface hardness (compaction and crusting), exposure of the roots of trees and shrubs above the ground, tree mounds, amour layer, soil pedestals, and buildup of soil against field barriers (Alim and Mumuli, 2010).

3.4 Digital Mapping of Soil Health Indicators

This activity will focus on predicting and creating spatially-explicit digital maps showing the spatial variability of functional soil properties in order to assess the impact of erosion on the health of soils in the Project area. The proposed minimum set of functional soil properties will be those that indicate soil fertility, quality and health; for example soil organic carbon and pH. The output digital soil maps will answer the following questions:

a) What are the spatial patterns of the different functional soil properties?
b) Where are the hotspots of soil fertility, health and quality decline for targeting CS-SLM interventions?

Based on the *scorpan* conceptual model of Digital Soil Mapping (DSM) (McBratney et al., 2003; Were et al., 2015), the spatial variability of the target functional soil properties will be explained by their relationships with the soil-forming factors (Eq. (2)). To achieve this, a wide spectrum of auxiliary EO and GIS data (i.e., environmental covariates) representing the different elements of the *scorpan* model will be retrieved from the GEE data archive, or other credible open-access data sources. The environmental covariates will include land cover, soils, geology, EO satellite data (e.g., Landsat 9 operational land imager (OLI) and Sentinel 2 spectral reflectance bands), EO satellite-derived vegetation indices (e.g., NDVI, Normalized Difference Moisture Index (NDMI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), Modified Soil-Adjusted Vegetation Index (MSAVI), Normalized Difference Soil Index (NDSI) and Desertification Soil Index (DSI)), climate (e.g., rainfall and temperature), DEM, and DEM-derivatives (e.g., slope gradient, slope aspect, curvature, topographic wetness index, LS factor and topographic position index).

$$S = f\,(s, c, o, r, p, a, n) \qquad \text{Eq. (2)}$$

where: S is the target soil attribute at the sampled location, which is a function of s (soil properties), o (organisms), r (relief), p (parent material), a (age or time), and n (space).

The foregoing environmental covariates will be either processed in GEE environment or using other appropriate open-source geo-computing environments, such as QGIS and R. The main processing operations will include resampling, sub-setting and transforming the environmental covariates to a common spatial resolution, extent and referencing framework. After processing, the environmental covariates will be stacked together and then intersected with the soil data points to extract the values of the covariates to the points. Next, the functional relationships between the environmental covariates and soil observations (i.e., f in Eq. (2)) will be modelled, and the spatial patterns predicted, using appropriate geostatistical and machine learning algorithms (e.g., regression-kriging and random forests). Lastly, the uncertainties associated with the resultant predictive soil maps will be assessed and quantified.

3.4.1 Application of EO UAV Data in Digital Soil Mapping

Similarly, the synergy between EO satellite and UAV data will be exploited to provide more insights into the dynamics of soil fertility. The processed UAV data will be used to generate high-resolution information, such as land cover types, spectral vegetation indices, DEM and DEM-derivatives, which will be incorporated as environmental covariates in the DSM process to predict and map the target functional soil properties within the 50 km^2 pilot area.

4.0 WORK PLAN

The project's activities outlined in Section 3.0 will be undertaken within 18 months. Table 1 summarizes the timings for each of the expected activities, outputs and deliverables. It can also be expanded to include the partners that will be responsible for each of the activities and the resources required.

Table 1: Work Plan

ACTIVITY	MONTH																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Output 1: TA coordination mechanism established																		
A1.1 Map relevant stakeholders and establish a TWG	■																	
A1.2 Organize consultative meetings with the TWG	■																	
A1.3 Organize a multi-stakeholder inception workshop		■																
Deliverables:																		
D1.1 Stakeholder mapping report	■																	
D1.2 Minutes of the consultative meetings	■																	
D1.3 Proceedings of the inception workshop		■																
Output 2: Project site selected and field data collected																		
A2.1 Select soil and UAV survey sites		■																
A2.2 Develop manuals/ protocols for field soil			■															

ACTIVITY	MONTH																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
survey and laboratory soil analysis			■															
A2.3 Field soil survey				■	■	■												
A2.4 UAV/ drone survey				■	■	■												
A2.5 Gender survey & analysis				■	■	■												
A2.6 Process and analyze field soil and UAV data							■											
Deliverables:																		
D2.1 Site selection report							■											
D2.2 Field soil survey & Laboratory soil analysis manuals							■											
D2.2 Soil survey report								■										
D2.3 Drone survey report								■										
D2.4 Gender analysis report								■										
Output 3: Soil erosion assessed and mapped																		
A3.1 Develop the RUSLE-GEE soil erosion modelling framework						■												
A3.2 Retrieve and preprocess spatial data for building the RUSLE model						■	■	■	■									
A3.3 Build and apply the RUSLE model in GEE environment									■									
Deliverables:																		
D3.1 RUSLE-GEE soil erosion modelling framework						■												
D3.2 Soil erosion risk map									■									
D3.3 Soil erosion modelling report										■								
Output 4: Functional soil properties and micro-nutrients digitally mapped																		
A4.1 Develop the SCORPAN-GEE digital soil modelling and mapping framework						■												
A4.2 Retrieve and preprocess spatial data for building the SCORPAN model to map selected soil						■	■	■	■	■								

ACTIVITY	MONTH																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
properties and micro-nutrients																		
A4.3 Build and apply SCORPAN models for selected soil properties and micro-nutrients in GEE environment																		
Deliverables:																		
D4.1 SCORPAN-GEE digital soil modelling and mapping framework																		
D4.2 Digital soil properties and micro-nutrients maps																		
D4.3 Digital soil mapping and modelling report																		
Output 5: Evolution of soil erosion overtime monitored and management actions planned																		
A5.1 Develop criteria and indicators to monitor the evolution of soil erosion overtime																		
A5.2 Develop guidelines for soil erosion modelling																		
A5.3 Produce policy briefs on the criteria and indicators and guidelines for soil erosion modelling																		
A5.4 Identify adaptation measures to address soil degradation and develop a Strategic Action Plan																		
A5.5 Organize consultative and validation workshops to present the Strategic Action Plan, indicators, policy briefs, and guidelines																		
Deliverables:																		
D5.1 Criteria and indicators for monitoring the evolution of soil erosion																		

ACTIVITY	MONTH																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
D5.2 Guidelines for soil erosion modelling											■							
D5.3 Policy brief on soil degradation by erosion														■				
D5.4 Strategic Action Plan (for soil conservation)															■			
D5.5 Proceedings of the consultative and validation workshops																■		
Output 6: Stakeholders trained and TA results disseminated																		
A6.1 Organize a 3-day capacity building workshop																	■	
A6.2 Disseminate the project outputs, lessons learnt and key messages														■	■	■	■	■
Deliverables:																		
D6.1 Training workshop report																	■	
D6.2 Evidence of the dissemination media (e.g., publications and websites)																		■

5.0 GENDER MAINSTREAMING

Gender equality and inclusion of men's and women's concerns and experiences will form an integral part of the design, planning, execution, monitoring and evaluation of this TA. To accomplish this, first, the CTCN gender mainstreaming tool will be used to develop a comprehensive Gender Action (GA) Plan. Thereafter, an analysis of gender dynamics in the project area will be conducted either through focus group discussions (FGDs), key informant interviews (KIIs), or literature surveys. The aim will be to examine the differences between men's and women's roles, levels of power, participation in decision-making, needs, constraints, opportunities, and access to and control over resources, as well as the implications of the TA activities for men, women and youth.

6.0 KNOWLEDGE COMMUNICATION AND DISSEMINATION

A detailed Knowledge Communication and Dissemination (KC&D) Plan will be developed to guide engagements with different stakeholders and research users to communicate specific messages; for example, the project progress, results and lessons learnt. The aim will be to strengthen the overall effectiveness, impact and visibility of the Project by enabling stakeholders to clearly understand the Project's objectives, activities, and results. Therefore, it will clearly outline the stakeholders (target audience), knowledge products, outputs or key messages from the Project, specific objective(s) for each target audience, and the communication channels (e.g., website and scientific articles) as shown in Table 2.

Table 2: Knowledge Communication and Dissemination Plan Template

Who? Stakeholder	**What?** Knowledge product or message to be communicated	**Why?** The stakeholder will use the knowledge product or message to:	**Communication channel/ tool**	**Responsibility**	**When?**
NRGD	*Digital soil fertility maps*	*Promote sustainable and spatially-targeted soil management practices*	*Technical report, posters, soil fertility atlas, workshop, conferences, journals, policy briefs, geoportal*	*RCMRD, TWG*	*March 2023*
NRGD	*Digital soil erosion map*	*Promote sustainable and spatially-targeted soil conservation practices*	*Technical report, posters, workshop, conferences, journals, bulletins, policy briefs, geoportal*	*RCMRD, TWG*	

7.0 MONITORING AND EVALUATION

A Monitoring and Evaluation (M&E) Plan will be designed (Table 3) based on the TA Response Plan as a framework that will enable the project team measure the project results and impact, as well as understand how its own activities contribute to progress towards the project objectives. Monitoring will be essential to ensure that the project team is implementing the TA according to plan; hence, data on the ways and the extent to which activities have been implemented and whether project milestones are being met will be collected. Evaluation, on the other hand, will aim at ensuring that the TA is successful in contributing to positive change for project beneficiaries; thus, analysis of whether the implemented TA activities, or the achieved milestones, have contributed to the desired change(s) in the relevant beneficiaries will be routinely performed. This will give a true sense of the impact results of the project.

The M&E Plan will include information about the indicators, activities, outputs, expected results (means of verification), and methods of data collection. Suitable quantitative and qualitative indicators will be identified to monitor the activities, outputs and outcomes of the TA. Besides being objectively verifiable, the indicators will also be specific, measurable, achievable, relevant, and time-bound (SMART).

Table 3: M&E Plan and Impact Statement Template

Outputs & activities	Indicator	Expected results (Means of verification)	Method & frequency of data collection	Comments
Output 1:				
Activities:				
A1.1				
A1.2				
Output 2:				
Activities:				
A2.1				
A2.2				

8.0 CONCLUDING REMARKS

In a nutshell, this Technical Implementation report has provided details of the key activities of the TA and how each of them will be implemented with the necessary scientific rigor to fulfill the set objectives. The spotlight is on the use of EO satellite and UAV technologies, as well as of advanced laboratory analysis methods to tackle soil erosion in Al Damar District, Sudan. The report has also presented a logical Work Plan, and provided guidance for the development of practical M&E, KC&D and GA Plans for this TA.

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