

END-OF-PROJECT TECHNICAL REPORT

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



JUNE 2024



ACKNOWLEDGEMENT

This Technical Assistance was implemented with the support of the United Nations Climate Technology Centre and Network through a project titled: *Soil erosion evaluation using advanced laboratory measurement methods to support climate-resilient agriculture and food security*. The support and invaluable contributions provided by all stakeholders, especially the Technical Working Group based in Sudan, in the production of this final project report is greatly appreciated. Special thanks are also extended to the Director General - RCMRD for the administrative and logistical support, as well as for guidance throughout the project life.

June 2024

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
GEE	Google earth engine
GIS	Geographical information systems
GPS	Global positioning system
ISRIC	International soil reference and information centre
MoAF	Ministry of agriculture and forests
NDVI	Normalized difference vegetation index
NRGD	Natural resources general directorate of the ministry of agriculture and forests
PSM	Predictive soil modelling
QGIS	Quantum GIS
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
WRB	World reference base of soil classification

TABLE OF CONTENTS

ACKNOWLEDGEMENT	i
LIST OF ACRONYMS.....	iii
1.0 INTRODUCTION	1
1.1 Background and Context	1
2.0 OBJECTIVES.....	2
3.0 MAIN ACTIVITIES, RESULTS AND ACHIEVEMENTS.....	2
3.1 Coordination Mechanism of the TA Established	2
3.2 Project Site Selected	4
3.3 Field Data Collected.....	6
3.3.1 Soil Survey.....	6
3.3.2 Soil Sample Preparation and Analysis.....	9
3.4 Soil Erosion Risk Mapped	9
3.5 CS-SLM Measures to Mitigate Soil Erosion Identified and Soil Action Plan Developed	11
3.6 Criteria and Indicators to Monitor Soil Erosion Developed.....	13
3.7 Digital Soil Functional Properties Mapped.....	14
3.8 Stakeholders' Capacity Built.....	16
3.9 Results of the TA Disseminated	20
4.0 CHALLENGES AND LESSONS LEARNT	21
5.0 CONCLUDING REMARKS	21
REFERENCES	22

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 soil functional 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 intended to map the spatial patterns of soil erosion risk and soil functional properties (e.g., soil organic carbon and pH), quantify the annual soil loss rates, and delineate the priority areas for Climate-Smart and Sustainable Land Management (CS-SLM).

Unfortunately, the NRGD had not had any opportunity to utilize and fully benefit from advanced EO and PSM technologies due to several 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. The TA was expected to enhance technological capacities by filling information gaps, providing physical and human capacities, and demonstrating the application 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. Ultimately, the soil monitoring systems will be strengthened and agricultural resilience enhanced.

2.0 OBJECTIVES

The goal of the TA was *to support climate-resilient agriculture and food security in Sudan*. This was to be achieved through the following strategic interventions:

- a) Digitally mapping soil erosion risk and functional properties;
- b) Developing a soil action plan to address the soil degradation issues;
- c) Developing the criteria and indicators for soil erosion monitoring;
- d) Developing guidelines for modelling and mapping soil erosion risk and functional properties;
- e) Building the capacity of stakeholders on mapping soil erosion risk and functional properties using GIS and EO techniques; and
- f) Disseminating results of the TA.

3.0 MAIN ACTIVITIES, RESULTS AND ACHIEVEMENTS

3.1 Coordination Mechanism of the TA Established

First of all, a technical working group (TWG) comprising 11 experts was established and the process finalized by official letters from the Undersecretary of Ministry of Agriculture and Forestry, Sudan. The TWG was chaired by the Director General of Natural Resources. The 11 experts were drawn from the:

- a) Ministry of Agriculture and Forests (MoAF)
- b) Higher Council for Environment and Natural Resources
- c) River Nile state (sub-national, farmer representative, agricultural research station, land use department, and Rahjhi [private soil laboratory])
- d) Dry land Centre of the Agriculture Research Corporation

- e) Remote Sensing and Seismology Authority (RSSA), National Centre for Research
- f) Institute of Desertification and Desert Cultivation Studies, University of Khartoum

Through consultative meetings (Figure 1), the TWG:

- a) Oversaw and supervised the implementation of the TA;
- b) Provided a technical overview and a high-level guidance at every stage of implementation;
- c) Accessed existing maps, surveys and technical analysis that could have been done;
- d) Discussed possible sites in which the TA could be implemented;
- e) Validated baseline data and approve field data collection protocol; and
- f) Revised final versions of the products, policy briefs and guidelines.



Figure 1: Consultations within the Technical Working Group

After the TWG was established to coordinate the TA, a multi-stakeholder inception workshop was organized at Paradise Hotel in Khartoum, Sudan from 18th to 22nd July, 2022 (Figure 2). The workshop was formerly opened by the Undersecretary Ministry of Agriculture and Forests.



Figure 2: Participants at the multi-stakeholder inception workshop

3.2 Project Site Selected

Out of the seven (7) districts in the River Nile State (RNS), Al Damar (Ad Damer, Ed Damer; Figure 3) was selected as the ideal site for implementing the TA by the TWG because it:

- a) had been adversely affected by climate change and land degradation processes, particularly, soil erosion by water and wind, which is the focus of this TA;
- b) hosted one of the four (4) government-funded food security projects in the RNS; thus, the data gathered during soil surveys and UAV operation was also to be utilized in the development of crop suitability maps for the food security site;
- c) had baseline data that was collected by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) in 2019;
- d) exhibited high spatial variability of soils; and
- e) was the capital of the RNS; hence, State support was guaranteed.

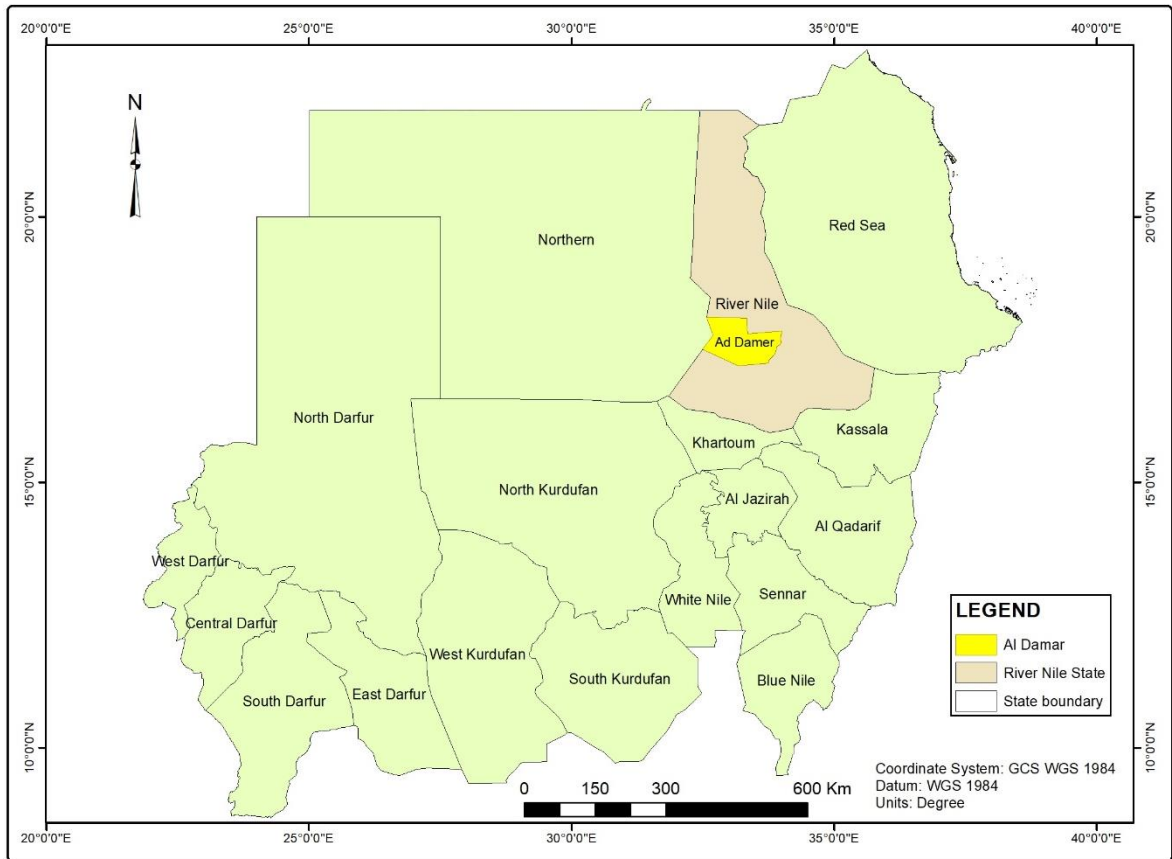


Figure 3: Location of Al Damar District in the River Nile State, Sudan

Al Damar lies between Latitudes $17^{\circ} 11' 9.6''$ and $18^{\circ} 6' 46.8''$ N, and Longitudes $32^{\circ} 28' 12''$ and $33^{\circ} 59' 45.6''$ 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 CaCO₃ 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>).

3.3 Field Data Collected

3.3.1 Soil Survey

Soil survey entailed 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 was developed to provide guidelines for office preparations, field observations and sample collection. It described in detail the field equipment and materials, sampling design, and specifications and requirements for soil sample collection, as well as for sample handling and packaging. In developing the field survey manual, reference was also made to the existing field protocols (Kenya Soil Survey Staff, 1987; FAO-SWALIM, 2007), previous soil mapping studies and literature. This manual will 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.

A variety of equipment and tools were used to collect soil data in the field, including the Munsell soil colour chart, soil auger (backhoe and 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, gunny bags, and standard profile and auger description forms (Soil Survey Staff, 1999; FAO-SWALIM, 2007).

Soil samples were collected at two (2) levels, each with different observation density. The first level of sampling only focused on the Food Security Project site (Jandea) within Al Damar using semi-detailed type of soil survey, whereas the second level covered about 125,000 ha around the Jandea using reconnaissance type of soil survey (Figure 4).

3.1.1.1 Semi-Detailed Soil Survey

At the Food Security Project site (5,042 ha), a semi-detailed soil survey was conducted at a scale of 1: 50,000 by soil auger and profile pits. For observations by soil auger, augering was performed up to a depth of 60 cm (or to a hindering layer)

in a grid pattern, with one observation for every 25 ha and a spacing of 500 m between observations. At each auger hole, general and site information, such as observation ID, date, surveyor's name, GPS 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 was recorded on a standard auger hole description form (FAO-SWALIM, 2007).

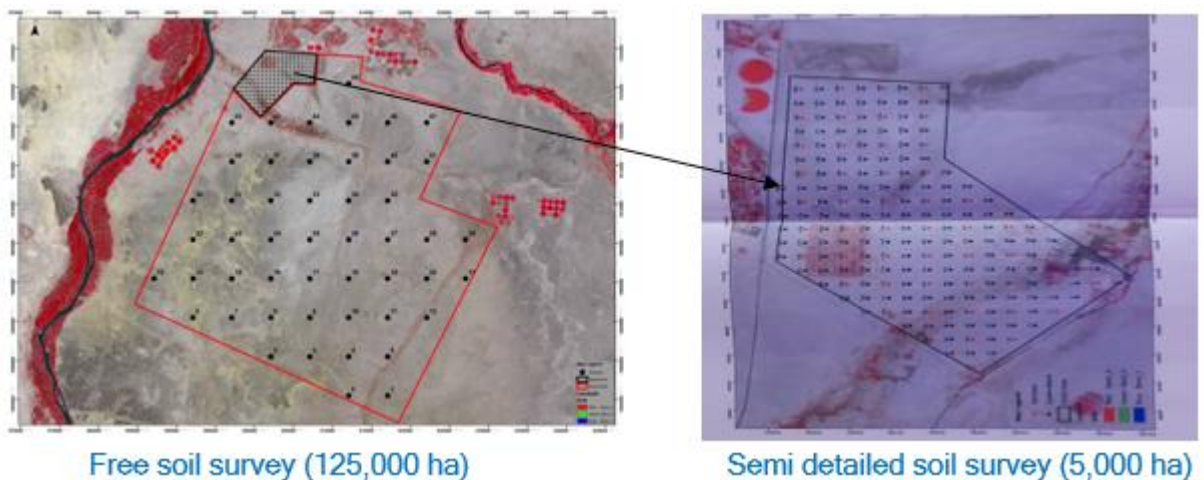


Figure 4: The two types of soil survey conducted

The soil auger observations were examined and characterized following FAO Guidelines (FAO-UNESCO, 1997; FAO, 2006) to delineate soil different mapping units. Thereafter, representative soil profile pits were sited and dug in the delineated soil mapping units (i.e., one profile pit per mapping unit). At each profile pit, the diagnostic horizons were identified, described and sampled for chemical and physical analyses at the Central Soil Laboratory of the NRGD (Figure 5 & 6). The information recorded on the soil profile description form were similar to those listed above for the observations by soil auger, with the only addition being the soil profile photographs. Lastly, the soil profiles were tentatively classified based on field data using the USDA soil taxonomy system (Soil Survey Staff, 1999).



Figure 5: Siting, digging and describing soil profiles in the field

3.1.1.2 Reconnaissance Soil Survey

In Al Damar District, a reconnaissance (free) soil survey was conducted at a scale of 1: 250,000, where field observations were primarily made by soil auger. That is, auger observations were made at random sites to a depth of 60 cm (or deeper if required), with one observation for every 1 km. The distribution of the auger observation sites took into account the spatial differences in physiography, geology, land use and soil types. Therefore, ancillary geospatial data, including EO satellite imagery and Digital Elevation Model (DEM) were compiled and superimposed to stratify the landscape into mapping units with similar combinations of relief, soil types, land use and geology for the randomization of

the observation sites. Each auger site was fully described and sampled for chemical and physical analysis.



Figure 6: The soil survey team working in the field

3.3.2 Soil Sample Preparation and Analysis

All soil samples collected in the field were transported to the Central Soil Laboratory of the NRGD for analysis. Once the soil samples were received at the laboratory, the information provided on the sample bags were recorded in a sample register. Unfortunately, the samples are yet to be analyzed due to the current political situation/ crisis in Sudan.

3.4 Soil Erosion Risk Mapped

This activity provided and executed a detailed, rapid, cost-effective and replicable framework for spatial assessment of land susceptibility to water erosion. The assessment (i) determined the spatial patterns of soil erosion risk, (ii) quantified the annual soil loss rates, and (iii) delineated the hotspots of soil erosion and areas for targeting priority CS-SLM interventions.

To generate the spatially-distributed soil erosion risk map (Figure 7), the Revised Universal Soil Loss Equation (RUSLE) model was used. This model, which was developed in the 1990s, was appropriate since it has been widely used by soil

conservationists to estimate the long-term average annual loss of soil through rill and sheet erosion. The model's popularity stems from 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). RUSLE integrates the five (5) major factors that affect soil erosion rates in any given landscape as expressed in Eq. (1).

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

where: A is the estimated mean annual soil loss ($\text{tons ha}^{-1} \text{yr}^{-1}$), R is the rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{h}^{-1} \text{yr}^{-1}$), K is the soil erodibility factor ($\text{Mg h MJ}^{-1} \text{mm}^{-1}$), 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 were 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 allowed for rapid development and delivery of digital soil erosion risk maps and automation of the entire soil erosion modelling process.

Results of RUSLE-based soil erosion modelling indicated that a huge part of Al Damar experiences moderate soil erosion, losing soil at the rate of about 10 tons per hectare annually ($\text{t ha}^{-1} \text{yr}^{-1}$), and some parts on the western side suffer from severe erosion, losing over $40 \text{ t ha}^{-1} \text{yr}^{-1}$ (Figure 7). A few places in the middle and on the eastern side of Al Damar experience high erosion rates, losing about $10 - 20 \text{ t ha}^{-1} \text{yr}^{-1}$. Appropriate remedial actions should be targeted at these sites to conserve the soils.

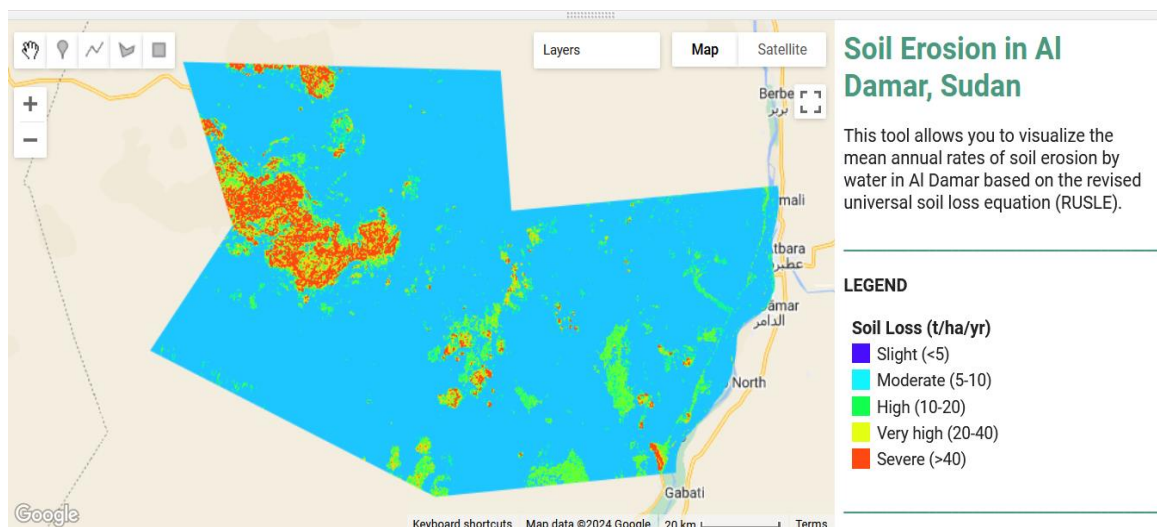


Figure 7: Spatial patterns of soil erosion risk in Al Damar

3.5 CS-SLM Measures to Mitigate Soil Erosion Identified and Soil Action Plan Developed

Appropriate CS-SLM interventions to be targeted at the delineated hotspots of soil erosion and priority areas were identified and selected in an all-inclusive and participatory manner, involving views and contributions from the key stakeholders, including the TWG members to encourage ownership, support and application of the measures. Thereafter, a *Soil Action Plan* was developed, which highlighted the key soil degradation issues, remedial actions, responsible entity to implement the remedial action(s), timelines, and the resources required (Table 1).

Table 1: Implementation matrix for the priority CS-SLM actions

LAND DEGRADATION ISSUE	PROPOSED SLM ACTION	RESOURCES NEEDED	COST (USD)	RESPONSIBLE	TIME
Soil erosion by water and wind	<p><i>Action 1: Reducing soil erosion by water and wind</i></p> <ul style="list-style-type: none"> ▪ Planting local drought-tolerant tree species as shelterbelts or windbreaks ▪ Contour farming ▪ Mulching ▪ Establishing physical soil conservation structures e.g., check dams 			Ministry of Agriculture and Forests	2024 - 2026

LAND DEGRADATION ISSUE	PROPOSED SLM ACTION	RESOURCES NEEDED	COST (USD)	RESPONSIBLE	TIME
	<ul style="list-style-type: none"> ▪ Strip farming ▪ Planting cover crops ▪ Intercropping ▪ Water harvesting 				
Salinity	<p><i>Action 2: Reducing salinity</i></p> <ul style="list-style-type: none"> ▪ Planting salt-tolerant crops and plant species ▪ Implementing efficient irrigation practices, such as drip irrigation to avoid over-irrigation, which can increase salt accumulation ▪ Applying excess water to flush out accumulated salts from the root zone and promote drainage (soil washing) ▪ Implementing crop rotation and diversification (to break the cycle of salt accumulation) 			Agricultural Research Corporation	2024 - 2026
Sodicity	<p><i>Action 3: Reducing sodicity</i></p> <ul style="list-style-type: none"> ▪ Liming if the soil pH is below 5 ▪ Applying a mix of lime (calcium carbonate) and gypsum (calcium sulphate) if the soil pH (CaCl₂) is in the 5 to 6.5 range ▪ Applying calcium-containing fertilizers ▪ Planting crops and plant species that are tolerant to sodicity 			Agricultural Research Corporation	2024 - 2026
Soil nutrient depletion (low P & N)	<p><i>Action 4: Reducing soil nutrient depletion</i></p> <ul style="list-style-type: none"> ▪ Applying appropriate inorganic and organic fertilizer after soil testing 			Ministry of Agriculture and Forests	2024 - 2026
Decline in soil organic matter	<p><i>Action 5: Increasing soil organic matter levels</i></p> <ul style="list-style-type: none"> ▪ Incorporating soil amendments and organic matter, e.g., compost, mulch, manure & biochar 			Ministry of Agriculture and Forests	2024 - 2026

3.6 Criteria and Indicators to Monitor Soil Erosion Developed

It was anticipated that: (i) the resultant soil erosion risk map and estimates would be used as a baseline for future monitoring and reporting on soil erosion dynamics in Al Damar District; and (ii) Potential monitoring sites would be selected within the hotspots of topsoil loss on the map for repeated measurements of soil erosion using similar methods at regular times. Therefore, this TA, in consultation with the key stakeholders and review of pertinent literature, developed the criteria and indicators that can be used to measure soil erosion at the selected monitoring sites. The indicators to measure and observe varied 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 tree roots above the ground, tree mounds, armour layer, soil pedestals, and buildup of soil against field barriers (Table 2).

Table 2: Potential indicators for monitoring soil erosion in Al Damar

Indicators	
Water erosion	Wind erosion
▪ Crusting of the topsoil	▪ Presence and amount of suspended particles in the air
▪ Occurrence of compacted soil layers (hard soil surface)	▪ Presence and extent of sand deposits
▪ Sealing of soil pores	▪ Frequency and duration of sand winds and dust events
▪ Absence of vegetation cover (bare soil)	▪ Changes in soil texture
▪ Formation of soil pedestals (pillars)	▪ Density of vegetation cover
▪ Building up of small channels (rills)	▪ Surface crust cover
▪ Building up of deep channels (gullies)	▪ Surface roughness
▪ Presence of sheet wash/ sheet erosion	▪ Presence of wind scouring/ blowouts and sediment depositions
▪ Changes in soil colour	▪ Degradation/ reduction of soil surface horizon
▪ Exposure of plant/ tree roots	
▪ Exposure of rocks	
▪ Exposure of fragipan, or armoured soil layer (stoniness)	
▪ Changes in soil rooting depth	
▪ Presence of tree mounds	
▪ Presence of sediments in drains, river banks, etc.	
▪ Building up of soils/ sediments against barriers (e.g., fences)	

▪ Decolourization of river water (muddy water)	
▪ Changes in soil texture	
▪ Changes in land use systems and practices	
▪ Presence of indicator plants (e.g.,)	
▪ Reduction in the thickness of topsoil (thin topsoil)	
▪ Reduction in crop yields and productivity	
▪ Decline in soil organic matter levels	

3.7 Digital Soil Functional Properties Mapped

This activity focused 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 original plan was to use the freshly collected field data in the predictive soil mapping exercise; however, the soil samples collected and sent to the Lab are yet to be analyzed. Therefore, the freely available legacy soil data from the International Soil Reference and Information Centre (ISRIC) was used. The set of functional soil properties were those that were available on ISRIC database and indicated soil fertility, quality and health; for example, soil organic carbon and pH.

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 soil functional properties was 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 were retrieved from the GEE data archive and other credible open-access data sources. The environmental covariates included 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).

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

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 were processed in GEE, QGIS and R environments. The main processing operations included resampling, sub-setting and transforming the environmental covariates to a common spatial resolution, extent and referencing framework. After processing, the environmental covariates were 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)) were modelled, and the spatial patterns predicted, using random forests. Lastly, the uncertainties associated with the resultant predictive soil maps were quantified.

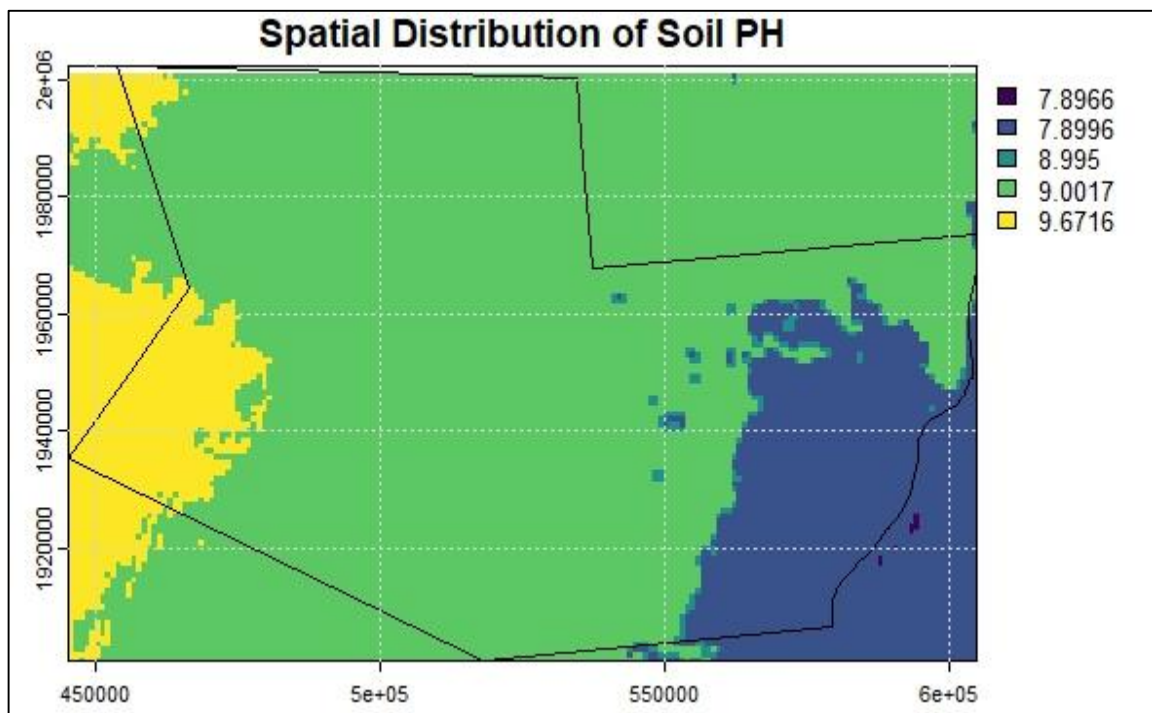


Figure 8: Spatial distribution of soil pH in Al Damar

The resultant digital soil pH map revealed that the soils of Al Damar are largely alkaline with pH values above 7 (Figure 8), while the digital SOC map showed that the soils are low in carbon (< 0.4 percent) (Figure 9).

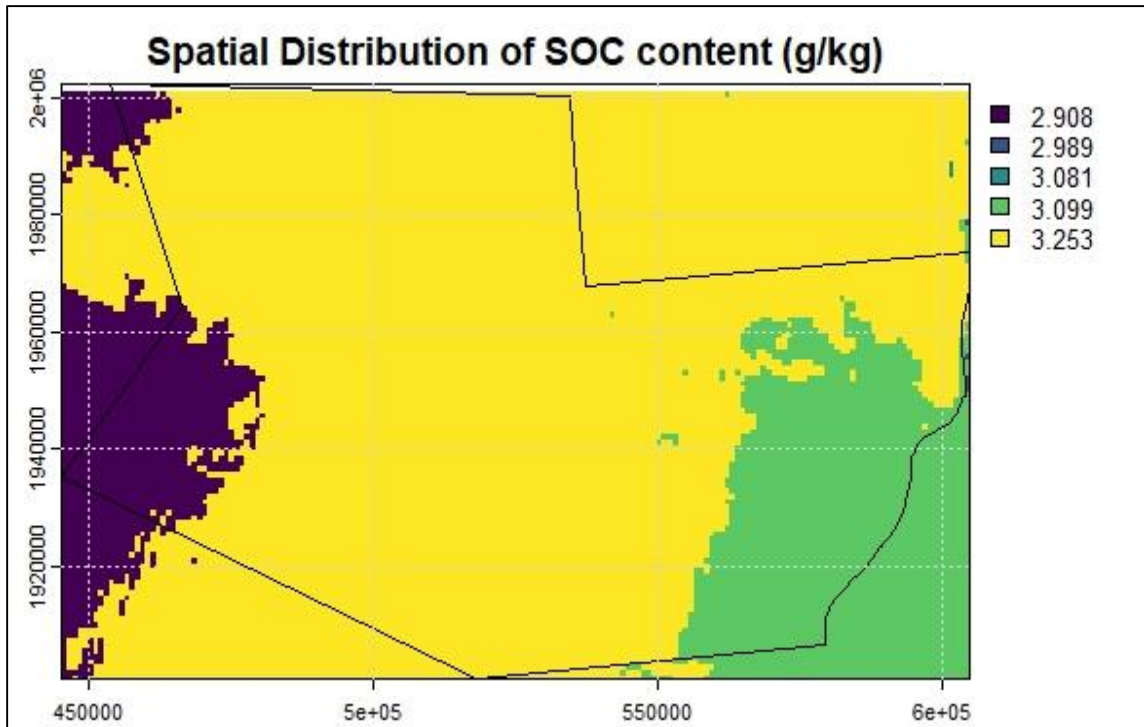


Figure 9: Spatial distribution of SOC (g kg^{-1}) in Al Damar

3.8 Stakeholders' Capacity Built

A six-day workshop was organized at the RCMRD in Nairobi, Kenya from 3rd to 8th June, 2024 with a view to building the capacity of stakeholders from various institutions in digital mapping of soil functional properties and erosion risk, and UAV data management (Figure 10 - 14). Seven (7) people from the Dry land Centre of the Agricultural Research Corporation, Institute of Desertification and Desert Cultivation Studies, University of Khartoum, and MoAF – NRGD were trained.

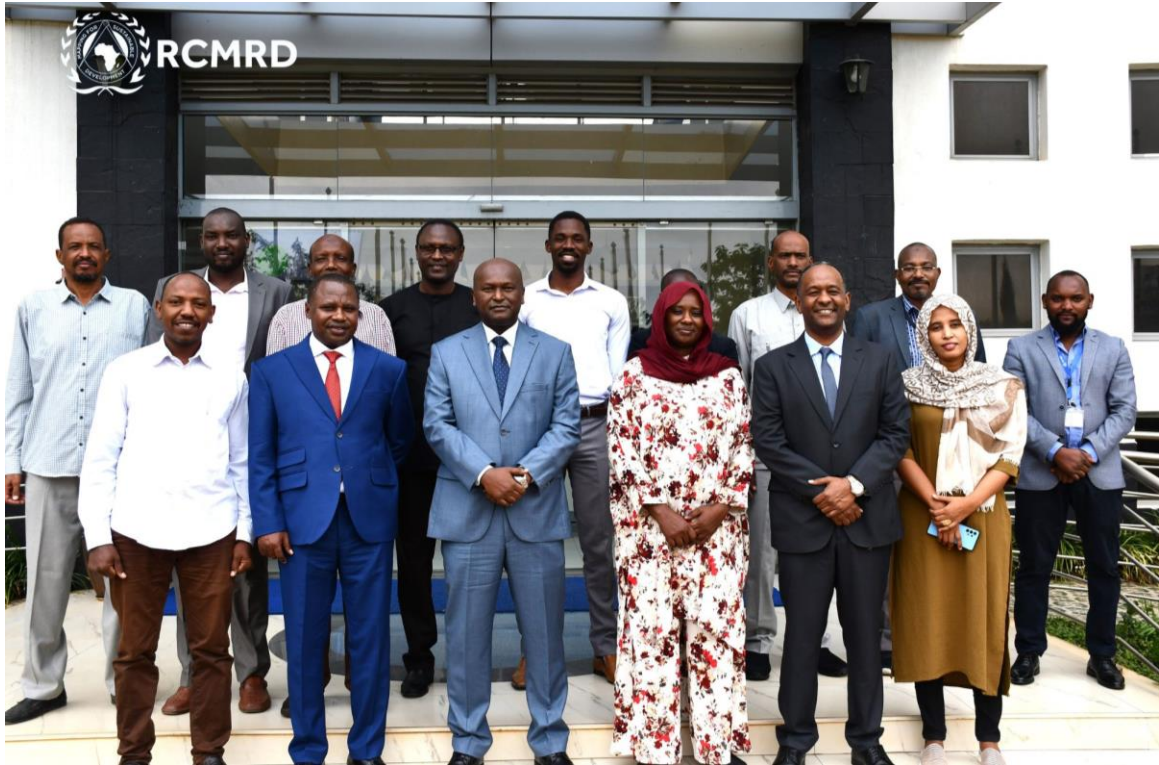


Figure 10: Group photo of the participants with the Director General – RCMRD and representative of the Ambassador of the Republic of Sudan in Kenya

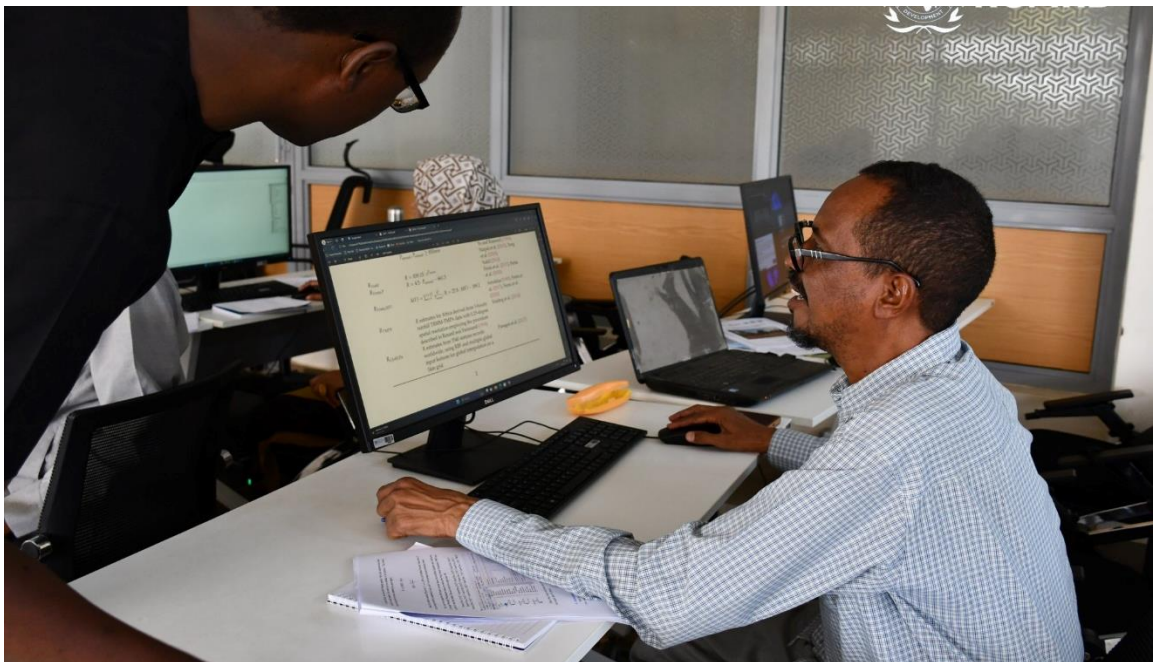


Figure 11: One of the RUSLE and Digital Soil Mapping training sessions



Figure 12: The trainees being shown how to fly a Drone (UAV)



Figure 13: A trainee flying a Drone during the practical session



Figure 14: The Director, Remote sensing, GIS and mapping - RCMRD presenting a certificate to trainees after successful completion of the training



3.9 Results of the TA Disseminated

The outputs, lessons learnt and key messages of the TA have so far been disseminated through publications (e.g., reports), posters, and RCMRD website and social media platforms (e.g., X and Facebook) (Figure 15 & 16).



Figure 15: Information about the training shared on RCMRD’s X account

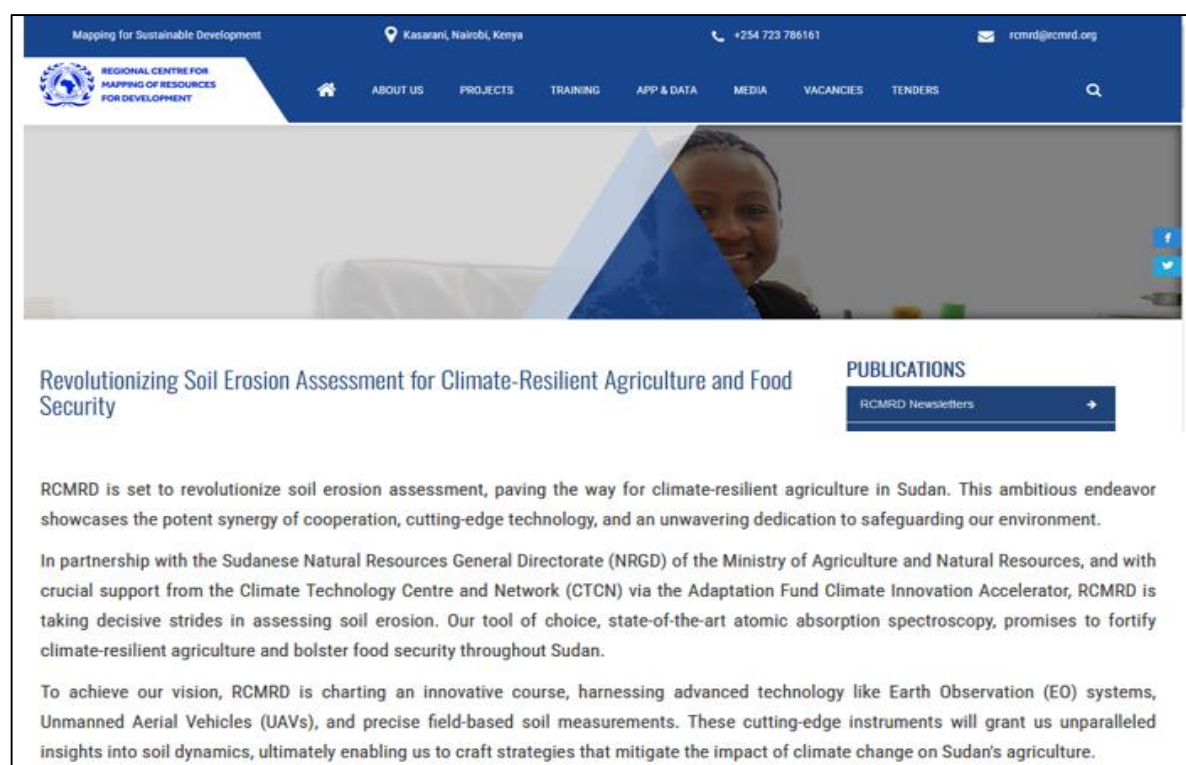


Figure 16: Information about the TA shared on RCMRD’s web page

4.0 CHALLENGES AND LESSONS LEARNT

The major challenge faced while implementing the TA was political unrest in Sudan. Due to this, certain in-country activities could not be carried out; for example, data collection using the UAV technologies and capacity building. In addition, soil sampling was conducted, but the soils could not be analyzed for the same reason; hence, legacy soil data had to be used for digital soil mapping. More detailed and accurate digital soils maps should be generated in the future once the analyzed soil data become available from the Central Soil Laboratory of the NRGD. Besides the political turmoil, excessive bureaucracy also impeded the transfer of funds from RCMRD – Nairobi to Sudan, as well as the utilization of UAV technology in the TA. It became practically impossible to transfer funds and also to get permission from the Survey Department to bring drones from Nairobi and operate them in Sudan. Hence, UAV data were not collected concurrently with the EO satellite and soil data as had been planned. Had funds also been transferred on time before the political crisis, the analysis of soil data would have been finalized. Overall, the situation affected the time available to implement the TA.

Inflation in Sudan is another challenge that the project had to grapple with. This caused RCMRD to spend more in implementing the TA activities. Specifically, RCMRD overspent by more than 20 percent, especially, on staff time and capacity development.

The key lessons drawn from this TA's experience is that risks associated with projects should always be thoroughly assessed and proper mitigation measures and alternatives spelt out before inception and execution. In addition, working with local stakeholders in coordination and implementation issues is paramount for the success of any development project.

5.0 CONCLUDING REMARKS

To conclude, this final technical report has provided details of the key activities, results and achievements of the TA from CTCN to NRGD. The spotlight of the TA was 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. Despite the fundamental challenges faced owing to the political crisis in Sudan, the

primary objectives of the TA, including *inter alia* mapping of the soil erosion risk were met. The tasks that could not be implemented, such as the Drone flight missions can be conducted when the situation improves. This calls for continued support and collaboration between RCMRD and MoAF - NRGD.

REFERENCES

- El Ghazali GEB, Abdalla WE, Elegami AAB., Baballa K., Sulieman YSM, El Mubarak FAY, Hamed HA (2021). Medicinal plants of the Sudan, Part VII: Medicinal plants River Nile State. National Centre for Research, Khartoum, Sudan, 77 pp.
- Elnashar A, Zeng H, Wu B, Fenta AA, Nabil M, Duerler R (2021). Soil erosion assessment in the Blue Nile Basin driven by a novel RUSLE-GEE framework. *Science of the Total Environment* 793, 148466.
- FAO (2006). Guidelines for soil description – 4th Edition. FAO, Rome, Italy. ISBN 92-5-105521-1.
- FAO-SWALIM (2007). Field survey manual: Soil, soil erosion, land use and land cover. FAO-SWALIM. Project Report No. L-01. Nairobi, Kenya.
- FAO-UNESCO (1997). Soil map of the world, vol. 1 legend, FAO-UNESCO, Paris.
- Fenta, AA, Tsunekawa A, Haregeweyn N, Poesen J, Tsubo M, Borrelli P, et al. (2020). Land susceptibility to water and wind erosion risks in the East Africa region. *Sci. Total Environ.* 703, 135016.
- Getu LA, Nagy A, Addis HK (2022). Soil loss estimation and severity mapping using the RUSLE model and GIS in Megech watershed, Ethiopia. *Environmental Challenges* 8, 100560.
- Kebede YS, Endalamaw NT, Sinshaw BG, Atinkut HB (2021). Modeling soil erosion using RUSLE and GIS at watershed level in the upper beles, Ethiopia. *Environmental Challenges* 2, 100009.
- Kenya Soil Survey Staff (1987). Manual for soil survey and land evaluation – Vol. 1. Miscellaneous soil paper No. M24. Kenya Soil Survey, Nairobi.
- McBratney AB, Santos MLM, Minasny B (2003). On digital soil mapping. *Geoderma* 117, 3–52.
- Papaiordanidis S, Gitas IZ, Katagis T (2019). Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in Google Earth Engine (GEE) cloud-based

platform. *Dokuchaev Soil Bulletin* (100), pp. 36-52, DOI: 10.19047/0136-1694-2019-100-36-52.

Soil Survey Staff (1999). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. United States Department of Agriculture, Agricultural Handbook No. 436. U.S. Government Printing Office, Washington, DC 20402.

Wang H, Zhao H (2020). Dynamic changes of soil erosion in the Taohe River basin using the RUSLE model and Google Earth Engine. *Water* 12, 1293; doi:10.3390/w12051293.

Wang W, Samat A, Ge Y, Ma L, Tuheti A, Zou S, Abuduwaili J (2020). Quantitative soil wind erosion potential mapping for central asia using the Google Earth Engine platform. *Remote Sens.* 12, 3430; doi:10.3390/rs12203430.

Were K, Bui DT, Dick ØB, Singh BR (2015). A comparative assessment of support vector regression, artificial neural networks, and random forests for predicting and mapping soil organic carbon stocks across an Afromontane landscape. *Ecological Indicators* 52, 394–403.