"Towards Sustainable Soil Management in the Face of Climatic Hazards: Assessment of Water Erosion in the Semi-Arid Tunisian Zone"

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ABSTRACT

The update of the SWC planning study for the Kairouan Governorate is part of the Watershed Management Framework Financing (FCGBV) project and the implementation of the national Water and Soil Conservation (WSC) strategy. This strategy, whose primary objective is the conservation and enhancement of natural resources, is based on the integration of SWC projects into agricultural development projects and on a participatory approach in the development of SWC management plans. For the Kairouan Governorate, areas moderately and highly susceptible to erosion represent approximately 250,000 ha, or 38% of the governorate's total area. Existing SWC

developments cover 153,000 ha, representing a development rate of 61%. This figure does not include traditional developments (tabias) carried out by farmers, which results in a higher development rate. Existing SWC developments in the Kairouan Governorate consist primarily of mechanical dikes and river structures, with 71 hillside lakes and 22 hillside dams. Given the scale and nature of existing SWC projects in the governorate, the average volume of water that can be mobilized by these various projects has been estimated at approximately 32 million cubic meters per year. The implementation of the SWC development plan selected for the Kairouan Governorate requires the mobilization of various material and financial resources, which largely determine its implementation schedule.

Keywords : water erosion, SWC developments, Kairouan Governorate, Tunisia.

INTRODUCTION

In the Mediterranean, soil erosion is a widespread phenomenon due to the region's harsh climatic and topographical conditions and sometimes inadequate agricultural practices. The high concentration of this phenomenon in Tunisia raises the question of its role in the siltation of water reservoirs[1,2,3,4]. The study of the current state of erosion constitutes one of the main elements of the diagnosis of the current situation carried out during this SWC planning study. Indeed, this study, which contributes to the identification of priority areas and the development of the SWC development plan for the Kairouan governorate in central Tunisia, one of the areas most affected by water erosion, was carried out based on the interpretation of topographic maps and Google Earth satellite images, as well as field surveys[4,5]. However, with the aim of preserving soil resources and ensuring the sustainability of agricultural development, erosion sensitivity studies are of increased interest for the development of SWC management plans, as they make it possible to identify the most erosion-sensitive and most productive areas requiring priority protection[6]. Thus, the erosion sensitivity map was developed using a multi-criteria approach combining several parameters influencing the formation and acceleration of erosive processes. It makes it possible to delineate areas that are more or less sensitive to erosion and, consequently, to identify the areas most exposed to the risk of erosion, which require protection through appropriate surface water

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management and sanitation plans.[7,8] It should be noted that the erosion sensitivity map differs from the current map in that:

Areas of high erosion do not correspond exactly to sensitive to very sensitive areas. Indeed, completely denuded rocky areas and highly degraded areas (badlands) are no longer susceptible to erosion[9].

Areas of low erosion do not necessarily correspond to areas of low susceptibility. Indeed, soft soils on gentle slopes, subject to violent runoff from mountains and hills, are susceptible to erosion. Thus, some areas of high erosion may reach a state of degradation such that they become relatively insensitive to erosion, while some areas are currently relatively unaffected by erosion but are threatened by various erosive processes, given their location (at the foot of mountains) and their characteristics (soft soils)[10,11,12].

Presentation Of The Study Area

The Kairouan Governorate is located in the center-west of Tunisia. It covers a total area of 660,522 hectares, or 4% of the country's total area. Given its geographical location, the Kairouan Governorate occupies a strategic position both regionally and nationally.

Given its geographical location, the Kairouan Governorate occupies a strategic position both regionally and nationally. Indeed, it borders the following six governorates [13,14]:

- The governorate of Zaghouan to the north,
- The governorate of Siliana to the west,
- The governorates of Sidi Bouzid and Sfax to the south,
- The governorates of Sousse and Mahdia to the east,

The city of Kairouan, which constitutes the capital of the governorate, is located approximately:

- 155 km south of Tunis,
- 57 km southwest of Sousse,
- 130 km northeast of Sidi Bouzid,
- 136 km northwest of Sfax

The governorate's location on the central axis allows it to maintain close ties with the country's main economic hubs (the Sahel, Tunis, and Sfax regions).

The project region has a semi-arid climate. This region is subject to dry and cold winds during the winter, dry and hot during the summer. It suffers from a water deficit due to high temperatures and lack of water withdrawal except during the autumn when we can have a little rain in the form of thunderstorms. These rains are known for their intensity and their strong energy, therefore their torrential aspect characterizes the phenomenon of infiltration to occur and causes an instant and violent runoff which favors the transport of materials and triggers the phenomenon of water erosion.

Figure 1. Location of the study area

It goes without saying that soil erosion and land degradation represent the overall regressive effect of the combined action of various factors (physical and biological) in the natural environment on the evolution of soil cover over time.

METHODOLOGY

Methodology Adopted

The methodology adopted for developing the erosion sensitivity map was inspired by that developed by EEC experts as part of the MEDALUS (Mediterranean Desertification and Land Use) project, whose main objective was to develop a desertification sensitivity map for Mediterranean countries.

This methodology, which aims to assess erosion sensitivity, is based on mapping and combining five main factors involved in erosion phenomena: soil, hydrographic network, climate, vegetation, and existing developments.

Pedological and geological maps, as well as slope, vegetation, and land use maps, provide all the parameters required to assess erosion sensitivity through its main factors. These factors are assessed based on the main parameters that comprise them. The following figure shows the diagram for developing the erosion sensitivity map using the MEDALUS method[15,16].

Sensitivity to erosion is determined by an ISE index (Erosion Sensitivity Index) obtained from the geometric mean of the four quality indices of the factors retained [17].

ISE = (IQS x IQR x IQV x IQC x IQA)$^{1/5}$

With:

IQS : Soil Quality Index,

IQR : Ravinement Quality Index

IQV : Vegetation Cover Quality Index,

IQC : Climate Quality Index

IQA : CES Management Quality Index.

Furthermore, for each factor, the quality index is obtained from the geometric mean of the scores assigned to the various parameters affecting the factor considered.

It should be noted that the selection methodology was adapted to the physical and socioeconomic conditions of the study region through the choice of parameters and their rating to assess the quality index of each factor.

The methodology used adopts a parameter rating ranging from a value of 1 (considered the best, having very little to no influence on erosion), to a value of 2, which is the highest value assigned to the parameters most influential on erosion (see attached map).

A general examination of the erosion sensitivity map shows that soils in the western part of the government are quite sensitive to erosion, while those in the eastern part are not very sensitive to erosion. Indeed, approximately 70% of the soils in the western part are moderately to highly susceptible to erosion, while approximately 90% of the soils in the eastern part are made up of areas of low to very low susceptibility.

Furthermore, according to this map, areas moderately to highly susceptible to erosion represent 38% of the total area of the government.

The following table shows the surface area (in hectares and %) of the different erosion susceptibility classes

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across the governorate.

Table 1: Significance of erosion susceptibility classes

Erosion Sensitivity Class	Importance	
	(ha)	(%)
1. Very Low Sensitivity Areas	189 650	29 %
2. Low Sensitivity Areas	217 770	33 %
3. Moderate Sensitivity Areas	179 950	27 %
4. Very High Sensitivity Areas	70 330	11 %
Total	**657 700**	**100**

An examination of this table reveals that:

- Areas seriously threatened by erosion, composed of highly sensitive soils, cover approximately 70,000 hectares, or around 11% of the governorate's total area.
- Areas moderately threatened by erosion, with moderately sensitive soils, extend over roughly 180,000 hectares, representing about 27% of the governorate.
- Stable or low-risk zones (with low to very low erosion sensitivity) span 407,400 hectares, accounting for 72% of the total area.
- Consequently, areas with moderate to high erosion sensitivity, which require short- to medium-term interventions, encompass about 250,300 hectares, or 28% of the governorate.

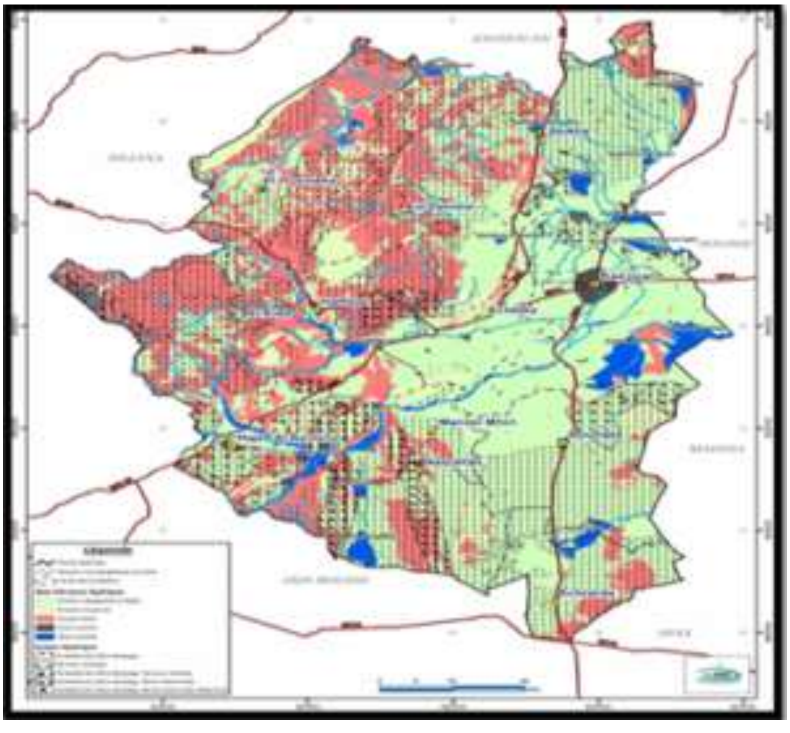

Figure 3. Map of the state of water erosion in the Kairouan Governorate

Sensitivity Test Results

We performed three sensitivity tests corresponding to percentages of 10, 15, and 20%. The following table summarizes the results of the various sensitivity tests [18].

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Table 2: Sensitivity Test Results

Sub-basin sensitivity	**Test N° 1 (10 %)**	**Test N° 2 (20 %)**	**Test N° 3 (30 %)**
v Sub-basins with little or no sensitivity (1-rank difference)	68 %	59 %	38 %
v Sub-basins with moderate sensitivity (2-rank difference)	23 %	26 %	40 %
v Sub-basins with moderate sensitivity (3-rank difference or more)	9 %	15 %	22 %

An examination of this table shows that

- For a 10% change in criteria scores, the change in sub-basin ranking did not exceed 1 rank for 68% of sub-basins, indicating a low sensitivity of the rating system to such a change.
- For a 20% change in criteria scores, the change in sub-basin ranking was 2 ranks or more for 41% of sub-basins, indicating that the rating system is moderately sensitive to such a change.
- For a 30% change in criteria scores, the change in sub-basin ranking was 2 ranks or more in 62% of cases, indicating a fairly high sensitivity of the rating system to such a change. We can therefore conclude that the scoring system becomes quite sensitive beyond a 20% uncertainty in assigning scores to the various criteria, indicating that the determination of criterion values must be done with a certain degree of precision.

On the other hand, we found that the sensitivity of the scoring system is higher for criteria with the most significant weighting, such as those relating to soil erodibility and infrastructure protection. Therefore, the values of these criteria must be determined with caution.

Final Ranking

The sensitivity analysis showed that the criteria scoring system adopted is not very sensitive to score variations of less than 20%, indicating that the average ranking adopted above remains valid even for a 20% fluctuation in criterion scores.

However, to account for variations in sub-basin rankings due to uncertainties related to determining the values of the various criteria, we grouped the sub-basins in order of priority into four groups, based on the average overall scores obtained.

It should be noted that the order of priority can be modified within each group, taking into account other specific criteria.

1st Group:

This first group includes the six sub-basins that obtained an overall score of 55 to 68 points and are considered first-order priority sub-basins.

2nd group:

This second group includes the four sub-basins that obtained an overall score between 50 and 53 points and are considered second-order priority sub-basins.

3rd group:

This third group includes the four sub-basins that obtained an overall score between 34 and 41 points and are considered tertiary priority sub-basins.

The following table shows the final ranking of the sub-basins and their distribution by group.

4rd group:

This third group includes the four sub-basins that obtained an overall score between 27 and 32 points and are considered low-priority sub-basins.

Table 3: Final Ranking and Priority Groups

Groups	Sub-basins	Overall score (Ng)	Final ranking	Order of priority
1st Group	1 – Oued Merguellil Amont	67,9	**1**	First priority
	2 – Oued Maarouf Aval	63,8	**2**	
	3 – Oued Jebbess	58,7	**3**	
	4 – Oued Marrouf Amont	58,6	**4**	
	5 – Oued Ghouil	56,6	**5**	
	6 – Oued Marrouf Amont	58,6	**6**	
2n group:	1 – Oued El Hatab	52,8	**7**	Secondary Priority -
	2 – Région Centre du gouvrnorat	52,6	**8**	
	3 – Oued Nebhana aval RD	52,0	**9**	
	4 – Oued El Kseub	50,5	**10**	
3rd group	1 – Oued El Hajel	41,1	**11**	Tertiary Priority
	2 – Oued El Khriouaa	40,8	**12**	
	3 - Oued Merguellil Aval	38,8	**13**	
	4 – Plaine de Sisseb-El Alem	34,3	**14**	
4rd group	1 – Unité de Nasrallah	32,0	**15**	- - Low Priority
	2 – Plaine de Kairouan	30,9	**16**	
	3 – Unité de Bouhajla-Cherarda	30,4	**17**	
	4 – Oued Zeroud Aval	26,9	**18**	

Preparation of the Swiss Development Plan

The following presents the steps involved in developing the comprehensive SWISS development plan for the Kairouan Governorate.

Given that the main objectives of SWISS developments are the protection of areas threatened by erosion and the mobilization of runoff water, the areas requiring development were considered to correspond roughly to:

- 70 to 90% of areas highly susceptible to erosion
- 40 to 70% of areas moderately susceptible to erosion
- 10 to 20% of areas not very susceptible to erosion

On this basis, and taking into account the surface area of existing SWISS developments in the various delegations, the area to be developed was approximately determined for each delegation. It should be noted that the works in poor condition were fully integrated into the development plan, while for those in average condition, their maintenance and preservation were planned for approximately 70% of their surface area.

Furthermore, a proposal within this CES development plan includes the planting of fruit trees, mainly olive trees, either directly on the annual croplands to be developed or to consolidate the banks in certain areas.

At the end of this final stage, the development of the governorate's overall CES development plan is being completed. This plan will be divided by type of action and by delegation and will be represented on the development map, along with the existing CES developments to be preserved and those in good condition. Thus, the components of the proposed development plan are made up of protective actions that have a positive impact on improving crop yields and other parts of directly productive actions, such as fruit plantations that increase agricultural production and pastoralism, as well as runoff water mobilization works that have a productive aspect.

Area to be developed

The overall CES development plan adopted covers the entire governorate, taking into account the development needs at the level of each delegation. Indeed, during the development plan development stages, a total area identified for net development of 57,000 ha was identified for arable land and rangeland, bringing the total developed area across the governorate to approximately 210,000 ha.

The following table shows, on the one hand, the gross area to be developed for each delegation, while specifying its distribution (in %) in relation to areas with different susceptibilities to erosion, and on the other hand, the area of existing CES developments and the net area to be developed.

An examination the results [19]:

- The total net area to be developed at the governorate level, which covers approximately 57,000 hectares, consists of 85% of areas highly susceptible to erosion, 62% of areas of moderate sensitivity, and 15% of areas of low sensitivity, after deducting the total developed area in average to good condition, which is 147,000 hectares.
- At the delegation level, the area to be developed corresponds to:
- - 70 to 90% of areas highly susceptible to erosion,
- - 38 to 73% of areas of moderate sensitivity to erosion, with the exception of the delegation of Chbika (30%),
- - 10 to 20% of areas of low sensitivity (low sensitivity), with the exception of the delegations of Chbika and Oueslatia (0%) and the three Southeast delegations (39 to 55%),

Priority Development Plan

Based on the comprehensive development plan developed for the entire governorate, and taking into account intervention priorities and the average annual rate of work, the Priority Development Plan has been established, which will be implemented over a 10-year period.

Based on an average annual rate of 3,500 hectares of new work to be carried out and 5,000 hectares of existing developments to be preserved, the area targeted for intervention under the priority development plan will be approximately 85,000 hectares to be completed over a 10-year period, corresponding to approximately 60% of the total area of work proposed for the entire governorate. This has led to the comprehensive development plan being divided into two phases. Thus, the priority development plan, corresponding to the first phase of the overall development plan, will cover a total area of 86,000 hectares, distributed as follows:

- 20,000 hectares of mechanical earthworks (cereals and olive trees),
- 4,500 hectares of spreading areas,
- 2,000 hectares of individual basins in olive trees,
- 8,000 hectares of rangeland development,
- 50,000 hectares of conservation works,
- 1,500 hectares of subsoiling

It should be noted that when allocating the developments selected by delegation, priority watersheds were taken into account, and that 50 to 60% of the planned structures were selected for the priority development plan, given their importance. Furthermore, given the importance of the various actions and works to be carried out and their unit cost, the total cost of the project will increase, corresponding to the priority development plan.

Furthermore, a schedule of physical achievements over a 10-year period has been established, and a breakdown of investments by year and by action has been determined.

The resources to be implemented to carry out the actions selected within the framework of the priority development plan have also been determined. These include both material and financial resources.

Finally, the economic viability of the project will be studied after the adjustment and approval of the proposed development plan, taking into account the current situation (situation without the project) and the future situation (situation with the project).

Project Cost

Based on the quantities of the various CES actions to be undertaken within the framework of the priority development plan, and the unit prices used by the ACTA General Management, the total cost of the priority development project was determined to be 46,450,000 DT.

Earthworks represent 17% of the total project cost, followed by conservation works (15%), fruit plantations (15%), followed by spreading areas (10%), pastoral plantations and biological fixation (9%), and hillside lakes (8%). Furthermore, given that the priority development plan covers a total net area of approximately 85,000 hectares (35,000 hectares of new land and 50,000 hectares of conservation land), the average development cost per hectare will be 550 DT/ha, which is reasonable and acceptable [20.21].

Furthermore, the total cost of the project will be distributed as follows:

- 88% to be borne by the administration, or 40,900,000 DT,
- 12% to be borne by the population, or 5,250,000 DT.

It should be noted that farmers' participation in the implementation of the priority CES development plan essentially consists of covering 60% of the total environmental cost of tree planting and consolidation planting, corresponding to the preparation of holes, planting, and irrigation.

CONCLUSION

The implementation of the CES development plan selected for the Kairouan governorate requires the mobilization of a range of material and financial resources that largely determine its implementation schedule.

These include, in particular, labor (regular and specialized), the engines required to carry out the various projects, and the fruit and livestock plants.

Furthermore, the success of the project depends on the implementation schedule for the various actions. This schedule must take into account the beneficiaries' level of support for the various actions and the priorities they have set, as well as the administration's ability to monitor and control the projects. Alongside the protection of soil resources and the mobilization of surface water, the implementation of the priority CES development plan selected for the Kairouan governorate will have several positive impacts on the socio-economic environment, highlighting the socio-economic benefits of the various actions planned within the framework of this development plan.

These impacts relate to the development of arboriculture, the improvement of the population's living conditions and farmers' incomes, and the quantitative improvement of agricultural production and fodder resources. All of these impacts represent a significant added value compared to the current situation.

In particular, on the social level, the planned actions will create several permanent and casual jobs.

At the same time, agricultural land located downstream of the areas to be developed will benefit, thanks to the CES developments, from a range of positive impacts such as :

- Flood protection for agricultural land, urban areas, irrigated areas, and basic infrastructure.
- Reducing siltation of hillside lakes.
- Recharging the water table.

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