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ASSESSMENT OF THE EFFECT OF BENCH TERRACING IN EL OGLA AND EL HADADA WATERSHEDS IN TUNISIA IN THE CONTEXT OF GULLY EROSION

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Abstract

The study of the erosive manifestation in El Ogla and El Hadada watersheds showed a strong and accelerated erosive dynamic. The aggression of the rains, the unstable nature of the Lower Eocene clays and the pressure of humans on the marginal lands seem to be at the origin of the instability of the slopes. Thus, the preservation of lands requires a colossal effort from the part of the State as well as the peasants. Unfortunately, the majority of developments have been implemented on an ad hoc basis and are far from being implemented comprehensively. In El Ogla and El Hadada watersheds, bench terracing is the most spectacular form of State intervention. It is considered by technicians as the unique solution for all forms of erosion. However, the appearance of forms of failure in various sectors cannot neglect the good functioning of some of them in the stability of the slopes and the reduction of the water slide. The objective of this applied research is to evaluate the behaviour of these benches as an interactive system with the other components of the natural environment based on photointerpretation, field monitoring and the results of the diagnosis of the balance sheet displacement of sediments obtained from the application of the isotopic method of Cesium 137. This assessment of bench terracing is largely based on the Bugeat formula, which seems to be the most appropriate method for determining the suitable dimensions of both height and terrace spacing.

Keywords: Water Erosion, Bench Terracing, Bugeat Formula, Sediment Retention.

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Introduction

The choice of this theme was not arbitrary but justified on a practical level. The motivational points for choosing this topic are diverse but they all converge on the problem of land degradation, especially with the persistence of water erosion despite the State's commitment to a development policy based on bench terracing. In recent years, there has been a worsening of damage observed even on developed slopes.

Throughout this work, we tried to evaluate the morpho-dynamic behaviour of these benches constituting the most spectacular form of State intervention in the two watersheds El Hadada and El Ogla. The norms and measures adopted are often inspired by hydrological and agronomic specialists (Hamza, 1988, 1992; Hamza & Hamou, 1995; Nasri, 1998, 2002 (a); Roose, 2004; Lacombe, 2007). Several studies have been focused on the bench terracing technique in Tunisia to recognise its benefits for farming society. Slah Nasri's work between 1995 and 2010 is considered the most relevant in terms of analysing the efficiency of these techniques in quantitative and qualitative terms (Nasri, 2002) (a).

The results of his experimental trials in Central Tunisia, with its lower semi-arid climate, served as a guide and reference for the preliminary general specifications of this ancestral skill (Azaiez, 2016; Azaiez, 2021 (b)). This made it possible to compare the results on a regional or local scale. The contributions of Hamza (1988) in the Oued Hatab watershed and those of Hamdaoui (2012) in the Zaghouan region were all crucial importance in the development of this study.

Other research has focused on the contribution of cultivated bench terrace systems in Assir region, where the topography is rigorous and the lithology predominantly crystalline (Azaiez et al., 2020). The quantitative assessment was carried out using the isotopic tracer method related to Cesium 137, which was applied to the middle course of the Wadi Abha. (Azaiez, 2021 (a)).

In the context of the loss of old know-how on the part of farmers, can we really judge that bench terracing is the unique solution to fight against all forms of water erosion?

To answer this question, it was preferable to follow three methodological approaches, comprising investigation and data acquisition, processing and analysis based on geoprocessing, statistics, and modelling. Finally, an interpretation method based on maps and summary tables gives quantifiable models on the loss or retention of sediments, essentially in the El Mssine watersheds, where the model of quantification of losses on the slopes built either in bench terracing or in dry stone cords.

Materials and Methods

The study area and the socio-environmental context of soil erosion: The two watersheds are part of Central-Eastern Tunisia. El Ogla takes its source on the heights of Kef El Azaiez Mountain, sideswiped on the middle courses by the two reliefs of Bou Slam and Edghafla mountains. It drains an area of 80 km^2. While El Hadada watershed is the mainstream of Fkirine Mountain (985m), it crosses very steep slopes and drains an area of 38 km^2 (Figure 1).

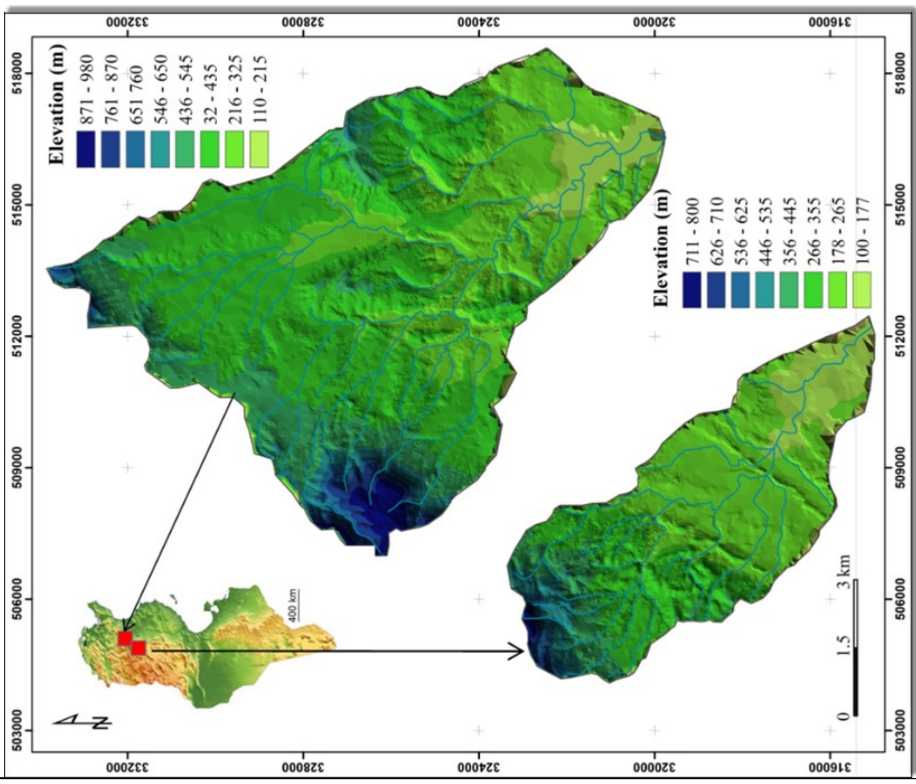
The El Hadada watershed is made of marl-clay-limestone geofacies, while the other one shows sandy-clay-sandstone geofacies (Figure 2).

Although soft outcrops and very low permeability are the least common (Figure 3), especially in the watershed of El Hadada Wadi, they occupy topographic positions capable of generating a concentration of runoff water. In this watershed, runoff is concentrated in the Souar corridor, dominated by the clay-marly outcrops of the lower Eocene. One of the signs of high water concentration and low permeability is the drainage density of 7.89 km/km2 in the Souar Formation.

At the total watershed scale, drainage density and hydrographic density have increased dramatically. In El Hadada watershed, having a more compact shape, the time of concentration of the flow is made after one hour and 52 minutes, according to a very high torrential coefficient of

Figure 1

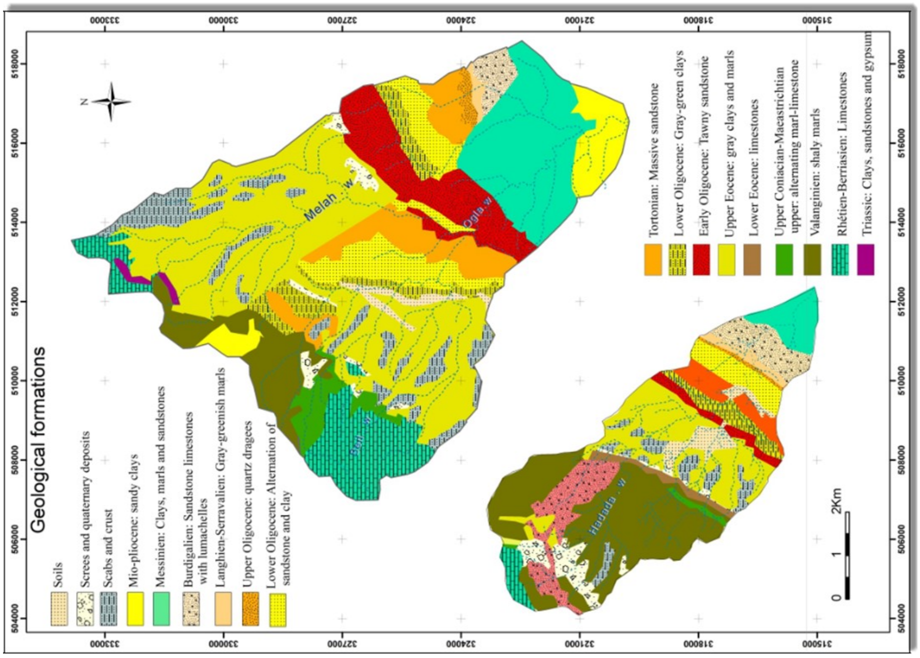
Location Map of El Ogla and El Hadada Watersheds



Source: STRM image and topographic map of Jebel Fkirine at 1/50000

Figure 2

Geological Map of El Ogla and El Hadada Watersheds



Source: Geological map of Jebel Fkirine at 1/50000

184.73 (results obtained by the application of three formulas of Passini, 1914, Giandotti, 1934 and Kirpich, 1940).

In Wadi El Ogla watershed, the situation is slightly less sensitive on the upstream and the middle courses, as the soft and plastic outcrops extend on the hillside with a more moderate slope and on more flat and vast plains. It's related to the relative topographic position of the impermeable layers (Figure 3).

This is demonstrated first because the lower drainage density is evolving at a slower rate compared to El Hadada watershed. Second, because the watershed has a more elongated shape, it has a slower concentration time and a lower torrentiality coefficient.

At the outlet, the flow monopolises a great power, after the slipping of the river Ben Halima Wadi causing frequent floods around the city of Nadhour during the exceptional rains. The most sensitive areas are Edghafla Mountain, Bent Saidane, Bouslam Mountain and the foothills of Hamadet Jrajif, Srassif and Douimiss.

The two catchment areas are affected to different degrees by erosion processes. At the end of the 19^{th} century, a brutal change in the agricultural system was established with the population explosion, colonisation and agricultural development of the marginal lands, reduction of the period of the fallow following a transformation of the system of culture and migration of people from rural areas into urban areas.

Hence, there was an urgent need for a curative intervention to conserve the water and the soil from both the farmer and the State to resolve the adverse effects of land erosion (Hamza, 1988, Azaiez 2016, Azaiez, 2020). Nearly 25 per cent of the land in the two watersheds is largely affected by gully, and further with suffocation and riverbank undermining. The stripping is manifested on watersheds with a moderate slope that is either bare, for olive or cereal vocation. More than half of the land in the Souar corridor is subject to intense gullying and local landslides (Figure 4).

In this corridor, land is divided equally between rangelands and cereals. This last agricultural specificity leaves the land exposed to the aggressiveness of autumn rainfall. The personal survey conducted among peasants with plots near the drainage axes shows the awareness of the local population to the grip of the ravine. In response to the harsh conditions of natural environment (limited water and soil resources, large slopes, huge expanses of soft rocks, capricious rains, and light or even absent vegetation cover) and the break-up of an old rather diversified production system adapted to the natural environment, the State has embarked on a varied anti-erosion policy, based mainly on the Bench Terracing in El Hadada watershed, and accompanied by dry stone cords in the second watershed El Ogla. The two watersheds are largely converted into bench terracing (Figure 5).

Until 2018, they covered 45 per cent of the total area of El Hadada watershed and 40 per cent of El Ogla watershed (Google Earth Pro 2018 Satellite Images). Having specific topo-structural-morphological and human conditions, the bench terracing will behave differently in each of these two watersheds.

The effect of these different works implemented in the two physical entities according to a typology that distinguishes the benches marked by their longevity despite the acceleration of the rate of erosion and the benches showed signs and symptoms of failure in several places was studied.

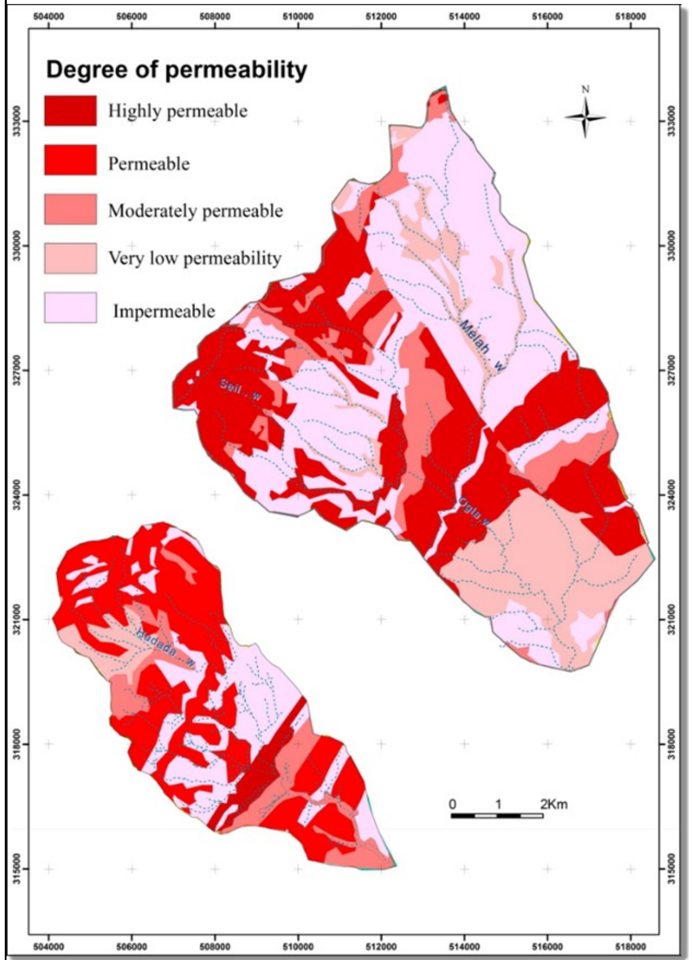
Results and Discussion

The bench terracing is a bead that cuts the slope horizontally at regular distances of 15 to 60 m depending on the value of the slope and an elevation between 70 cm and 1.20 m. The benches take the form of "a broad, reduced and constant strip of land with a bead and a ditch delimiting the bands of crops and are made mechanically or manually" (Azaiez, 2016).

The purpose of these benches is to intercept runoff water and to stop the detachment of soil

Figure 3

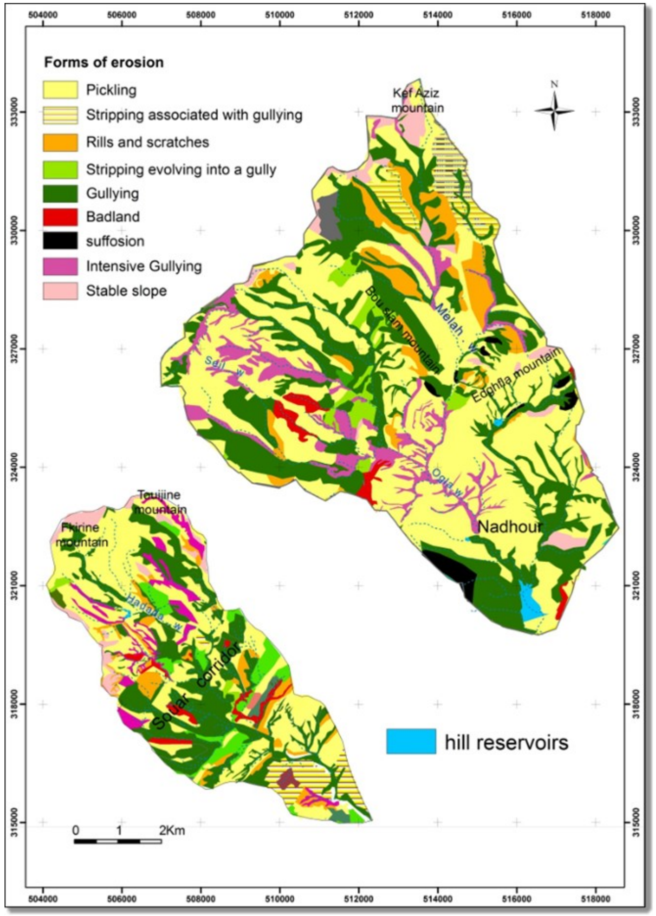
The State of Permeability in the Two Watersheds



Source: Geological map of Jebel Fkirine at 1/50000 and the results of the percolation test in situ, 2014

Figure 4

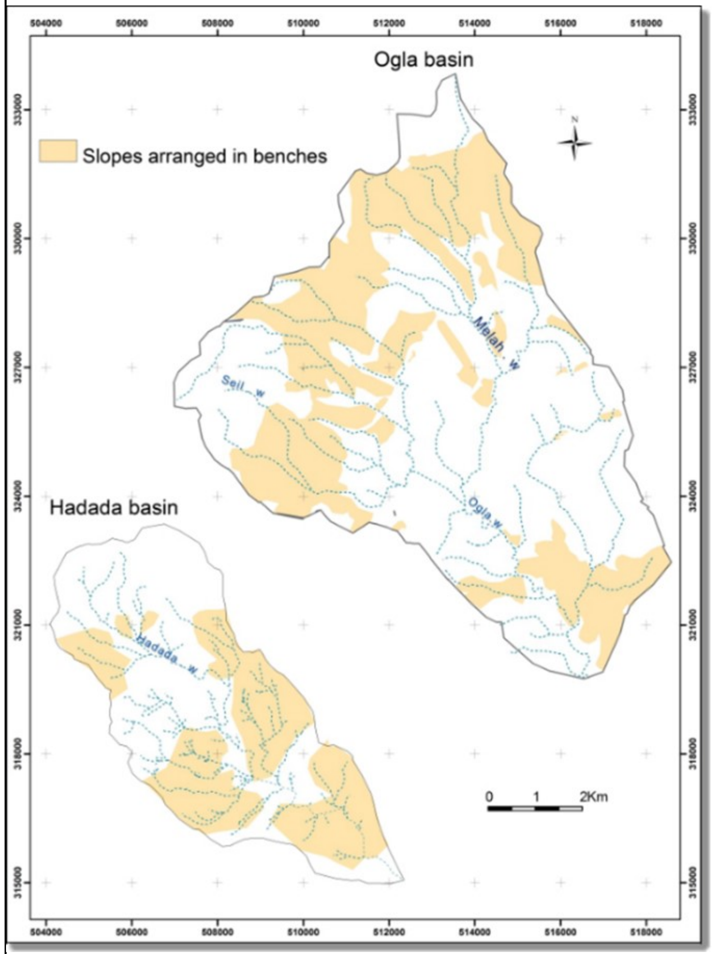
Distribution of Erosive Processes in El Ogla and El Hadada Watersheds



Source: Google Earth Pro 2018 Satellite Images, field research and aerial photos, 2000

Figure 5

Distribution of Bench Terracing in Two watersheds El Hadada and El Ogla until 2018



Source: Agricultural map, 2003 and Google Earth Pro 2018 Satellite Images, field research and aerial photos, 2000

Figure 6

Partially Infiltrating Benches in Functional Condition on the Slopes of El Hadada Basin

Source: Azaiez Naima, 2016

elements and its gullying. The developed bench terracing system "delays flow improves infiltration on the slopes and allows floods to be clipped by avoiding massive influx of water into reservoirs and considerably reducing the siltation of small reservoirs" (Hamza and Hamou, 1995; Nasri, 2002; Azaiez, 2016; Azaiez & Hamza, 2021).

Benches are of several types – those having partial retention, total retention, seepage and drains - that are supposed to evacuate excess water from the bench terracing ditches via natural or artificial outlets (Nasri, 2002). Several formulas make it possible to determine the unevenness and the spacing of the benches and the most important ones are those of Bugeat, Ramser, Nicolas and Saccardy.

Bugeat method is the largest one used in Tunisia based on the following two equations:

The distance (E)

(E) =2.2+8 * P (m)

With: P: slope in decimal

and the altitude difference (H)

(H) =8+2.2 /P(m)

With P: slope in decimal

Careful observation of the different sectors shows that these hydraulic structures have favoured good slope stabilisation and good water retention. They discharge runoff water in complete safety when it is in excess (Photo 1 and Figure 6), and good soil maintenance (Roose, 2004; Nasri et al., 2002; Azaiez, 2016, 2020). However, in other places, these benches are undergoing rapid damage and some slopes have experienced a re-operation of the old ravines and several others have settled in ex nihilo from the bead (Figures 6 and 7).

The benches are among the key protective structures highly sought by the local population in most areas of the two watersheds. More than half of the surveyed population wants the bench terracing to be planted on their own plots that are affected by erosion to different degrees and by multiple erosive processes. The benches that are most susceptible to erosion are those that exceed 1.20 m in height. In this context, Slah Nasri (2002) emphasised the best results of the partial retention benches compared to those of total retention.

During the survey, nearly 50 per cent of farmers who are not beneficiaries of CES work (Soil and Water Conservation) wanted to use bench terracing and treatment of ravine heads on their lands that are located on medium slopes. According to this small presentation, an attempt has been made to give a general assessment of the various behaviours of the benches. However, an evaluation of the impact of the bench terracing on the control of erosion and the contribution to the reduction of siltation of hill dams must be given. It is worth noting that at the scale of the study area, there are no pilot micro-basins to test the effectiveness of these structures in a precise way.

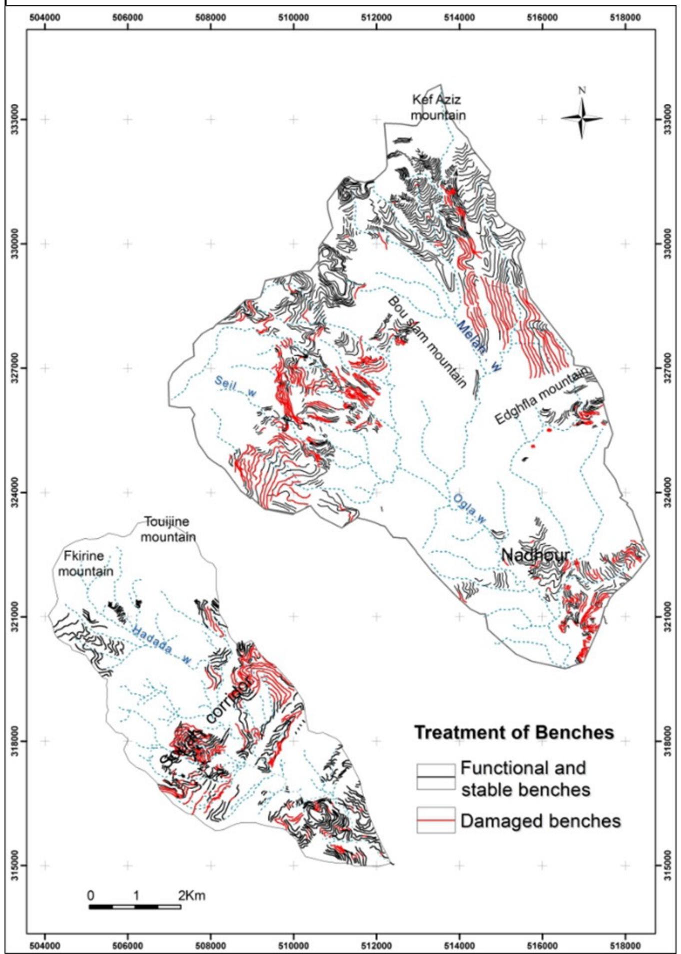
Thus, to do so, we based our evaluation on the directories that measure siltation in El Ogla and Saadine hill dams, on the results of the experimental research of Slah Nasri (2002) and on the results of Cesium-137 analyses that permitted to determine the enrichment rate of sediments trapped against teens on the benches in El Mssine wadi watershed.

Evaluation of the Effect of Bench Terracing in the Two Watersheds: To make this assessment, the results of the experimental work of Slah Nasri were considered. Field measurements and Arc Gis geoprocessing were carried out to verify the inter-bench terracing space, and some laboratory analyses were completed to assess the suitability of each sector for the establishment of the benches (Figure 7 and Table 1).

Benches Marked as Structures with High Water and Sediment Retention Capacity: Several sectors experienced good stabilisation of the river after a massive work of the State to implement a series of benches to mitigate the adverse effects of water erosion and reduction of runoff water slides. These positive results were observed even on sides with a considerable slope notably to Bled el

Figure 7

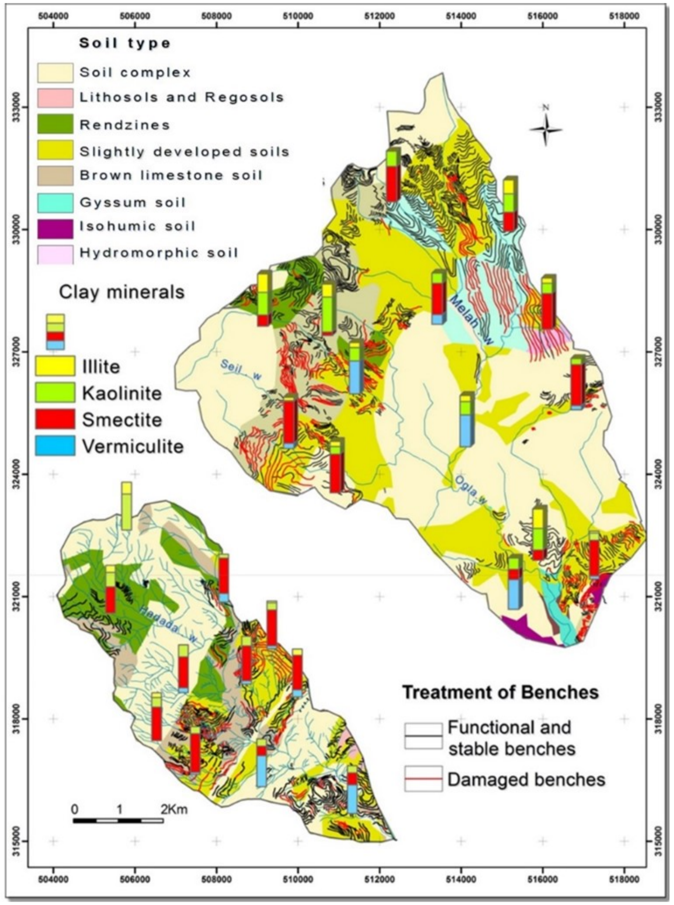
Damaged Benches in the two Watersheds El Ogla and El Hadada



Source: Google Earth Pro 2018 Satellite Images, field research and aerial photos, 2000

Figure 8

Operating Conditions of Bench Terracing based on Mineralogy Spectrum of Clays in the Two Watersheds El Hadada and El Ogla (results of mineralogy analyses, 2013/2014)



Source: Agricultural map, 2003 and Google Earth pro 2018 Satellite Images, field research, aerial photos, 2000 and results of XRD analysis.

Table 1

Estimated Specific Length of Breaches and Damaged Benches in El Ogla Watershed

Zones	Total length of bench terrace (m)	Total length of breaches (m)	Specific length of breaches (m/100 of bead)
Edghafla mountain	4172.1	0	0
Hmadet Douimiss	923.0	4	0.4
Sidi Dhghim	937.0	30	3.2
Ouled Achouich	1334.5	34	2.5
Henchir Brouta	2238.7	74	3.3
Hamadet Damous	423.0	72	17
Ain Rmil	1141,9	0	0
Douar Jlass1	831.5	0	0
Douar Jlass2	1303.0	0	0
Ar-Rwguib	2883.2	0	0
Sidi Abdessattar	1590	39	1.41
Draa ben Joudeur	2756.8	126	4.6
Mean	**1722.2**	**28**	**2.75**

Source: Hamdaoui. M, 2012, Azaiez, 2016 and Google Earth Pro 2018 Satellite Images

Mahrouka, upstream of Wadi Sekrouna in the El Hadada watershed (Table 2) and in the sectors of Aïn Abdessattar, Aïn Rmil, Douar Jlass, Ar-Rwaguib, Edghafla Mountain and Hamadet Douimiss in El Ogla basin (Table 1). This raises the question of the technical, physical, and geotechnical conditions that have guaranteed their proper functioning. Three facts are at the origin of this high efficiency: the inter-bench spacing, the mineralogy of the clays, the follow-up and the biological fixation of the bulges ensured by the farmers and the local authorities.

Table 2

Estimated Specific Length of Breaches and Damaged Benches in El Hadada Watershed

Zones	Total length of the benches (m)	Total length of breaches (m)	Specific length of breaches (m/100 of bead)
Henchir Ain Tamala	19530m	727.2m	3.72m/100m
Dar Chaouch	16373m	774.6m	4.7m/100m
Bled el Mahrouka	10626m	0	0
Sekrouna wadi	2932	0	0
Henchir el Haouita	9804m	276.2m	2.81m /100m
Henchir Souar	36992m	1974m	5.33m/100m
Hamadet Edeba	43935m	775.0m	1.76m/100m
Mean	**139544**	**4501.7**	**3.22**

Source: Azaiez, 2016 and Google Earth Pro 2018 Satellite Images

It should be noted, however, that there is a well-adapted spacing between benches and a difference in altitude. On average, the two watersheds record almost the same specific length of the breaches and collapse terrace embankments, which is around 2.75m /100m bead for El Ogla watershed and 3.22m / 100m bead for El Hadada.

Knowing that most of the bench terraces are in good working order and very little are affected by the opening of the breaches, those properly installed at the inter-bench spacing were defined by the Bugeat formula (Tables 3 and 4). In terms of evaluation and comparison, it was necessary to start with preliminary work on the field and Arc Gis programme to determine the length of open breaches in each sector so that later the direct causes of the failure of some benches could be determined.

Table 3

Inter-benches Spacing (Measured and Estimated According to Bugeat's Formula) in El Ogla Watershed

Zones	Measured spacing (m)	Estimated spacing (m)	Slope %	Observations
	34	25.38	13.33	
Henchir Ain Tamala	60	50	11	overestimated
	47	37.69	7	
Dar Chaouch	46	25.62 m	14.28	
	53	67.4 m	3.5	**underestimated**
	54.5	46.51	6.87	
	36.15	27.39	11.59	
Bled el Mahrouka	153m	74.1m	3.1	overestimated
	115m	42.43m	8.4	
	30	16.06	33.3	
Henchir el Haouita	20m	32.93m	8,72	**underestimated**
	25m	23.83m	21.01	
Henchir el Haouita)	30	14.8	41	
	100m	26m	12,5	overestimated
	73.33m	21.1m	22.5	
Souar	50m	26	12.5	

Source: Hamdaoui. M, 2012, Azaiez, 2016 and Google Earth Pro 2018 Satellite Images

This work was started by Hamdaoui in 2012 in El Ogla watershed and completed in 2014 in Wadi El Hadada watershed as part of a doctoral thesis (Tables 1 and 2).

According to this formula, the spacing between the ridges remains solely a function of the slope without considering the lithology, the vegetation cover, and the competence of the hydrographic network, which is estimated through a flow coefficient.

A study of Sbikha and Oueslatia showed that the capacity storage of recent 1m high benches, carried out as part of the second national water and soil conservation strategy, is in the order of 1000 m3/ha, i.e. a linear capacity of 6.3m3/m benchmark, largely exceeding the region's runoff capacity (CNEA, 2008). Compared to other adjacent watersheds, we report the study conducted by Slah Nasri (2002) on the watershed of Wadi El Gouazine. The efficiency of these benches comes from a multi-approach work based not only on the distance determined by the empirical formula of Bugeat but also through the simulation of rainfall and the development of hyetograms type for recurring showers to determine the shape of the floods and to properly size the spacing and heights of the benches. As a result, the setting up of benches between 1996 and 1997 resulted in a good reduction of the runoff coefficient (from 4 to 30 per cent before development and 1 to 9 per cent after development).

Three years after the implementation, the sedimentation volume collected in the lake was zero due to the reduction of the abrasive energy of the runoff water, but the problem of erosion is still posed for inter-bench spaces (Nasri, 2002). Some of the benches are adapted to slope and lithology. This assessment of their adaptation is based on field observation in the first place and on all the diffractograms of mineralogical analyses of clays and marls obtained by X-ray diffraction. Overestimated Field surveys in El Hadada watershed allowed to follow a state of fattening of some slopes in fine sediments, located downstream of each spacing inter-bench and against the ridges of the next bead in the direction of the slope.

This type of bench can be found on the slopes overlooking Sekrouna Wadi, installed on Kaolin clays, stable, firm, consistent and implanted in an inter-bench spacing underestimated relative to the distance defined by Bugeat. As a result, Jurassic clays and clay-marly Cretaceous outcrops show a better ability to accommodate and preserve bench terracing. In return, the clays of the formation Souar (Eocene Inferior) are strongly sensitive, on which the benches are quickly damaged by multiple erosive processes (Figure 7). In the second watershed of El Ogla, we noticed a different behaviour and a different adaptation of these benches since we are in an Oligocene clay-sandy geofacies and clayey-marl of the Lower Eocene. The Messenian clays contain more Illites, Kaolinites and Vermiculites, which reduced the specific length of the breaches to a minimum (Douar Jlass 0m/100m bead and Hamadet Douimiss 0.4m / 100m bead) (Figure 8).

The Bench Terracing Provides a Functional System with the Biocorridor Plants: In certain areas, the benches were successful in blocking the opening of new ravines, thanks first to a low inter-bench spacing and then to the planting of plant species with a well-developed root system capable of maintaining the soil. Of these old benches installed in the early sixties, 13 are currently barely retaining sediment because of their depreciation.

The series of Aleppo pine trees that have been planted today have reached a remarkable phrenological stage. These trees with their skeleton and density have contradicted the concentration of the flow although the slope is considerable (Azaiez, 2016).

This trial was based on the experimental study of Slah Nasri, the CNEA study and the contribution of the diagnosis of sedimentary balance made through the Cesium 137 method. A study done in Central-Eastern Tunisia has shown that the storage capacity of the recent 1-metre-high benches, built as part of the second national water and soil conservation strategy, is of the order of 1000 m3/ha which corresponds to a linear capacity of 6.3m3/m of bench which is well above the region's runoff capacity (CNEA, 2008).

Compared to other adjacent watersheds, we note the results of the experimental study by Slah Nasri (2002) on Oued El Gouazine watershed. The efficiency of these benches comes from a multi-approach work. This work was based not only on the distance determined by the empirical formula of Bugeat but also on the simulation of rainfall and the development of hyetograms type for recurring showers in order to determine the shape of floods and to properly size the spacing and heights of the benches. As a result, the installation of benches between 1996 and 1997 was efficient in reducing the runoff coefficient (from 4 to 30 per cent before the development and 1 to 9 per cent after the development). Three years after the implementation of these developments, the sedimentation volume collected in the lake was zero due to the reduction of the abrasive energy of the runoff water. However, the problem of erosion is still present in the interstitial space benches (Nasri, 2002).

According to Table 5, a comparison was made between the bench terracing and the dry-stone cords from the point of view of efficiency. The specific retention of the benches is in the order of 1027 m3/ha, whereas it does not exceed 1.75m3/ ha for dry stone cords. Indeed, over the years after the installation of the benches, the water retention capacity decreased gradually under the effect of the damping of the beads (2.5 times).

In contrast, the sediment retention capacity increases by more than six times. It should be noted though that the capacity, still high of the old benches terracing in terms of water retention, can be overestimated because of the high density of the bench terracing per hectare (Table 5). The positive impact of the installation of these benches in terms of sediment retention is also proven by the Cesium137 radio nuclear method. Thus, the map and the histograms obtained after a geoprocessing under Arc Gis showed that the bench terracing in the experimental sub-basin of El Mssine Wadi were able to retain between 6 and 8 t/ha/ year (Figs 8 and 9). It should be noted that this retention is much more considerable against the walls of cords in dry stones. In these areas, the sediment retention varies between 7 and 11 t/ha/year depending on the slope of the hillside. The state of these cords, their monitoring and their control was due to either the State or the peasants' work.

Different Forms of Failure of Bench Terracing and Their Causes: Damaged benches are the most common forms in the rural landscape, especially in the watershed of El Hadada Wadi despite their persistence in other places. The opening of the breaches threatened 27 per cent of all slopes of Wadi el Ogla watershed. The situation has become more of a worry in Wadi el Hadada watershed since the breaches affected 32.26 per cent of these benches.

The breaches that open are of sub-metric size and we can even witness a virtually total disappearance of the beads over hundreds of metres in highly favourable lithological conditions. The most affected benches are located on the middle course of Seil Wadi, the eastern part of the watershed of Wadi El Mssine, Hamadet Damouss and Henchir Souar. The causes of this failure take both a human and natural dimension.

An Overestimated Inter-bench Spacing: On average, between the two watersheds, all the benches installed are overestimated by 1.74 times compared to the gap required by the Bugeat formula. In some places, this index can reach 4.71 times in El Ogla watershed and 3.83 times in El Hadada watershed. Out of 12 areas studied in El Ogla watershed, there was a total of nine sectors in which the sampled benches were overestimated (sometimes more than 4.5 times) and only three sectors were underestimated (Hamdaoui, 2012).

In El Hadada basin, more than nine areas were surveyed in which the inter-bench spacing is overestimated. As a result, the value of the inter-bench distance plays an important role during erosion processes, especially during the onset of intense and continuous rainfall. The more the distance between two benches is overestimated, the more the central zone between the two benches is threatened by a re-operation of the runoff.

The length of the slope encourages the runoff to acquire energy again and the ability to dig scratches and channels in the central part and to open breaches on the beads. The heavy autumn rains that occur after a long period of drought are the ones that will take advantage of the deep desiccation slits. More than 27 per cent of the benches surveyed in El Ogla watershed are affected by the erosion breaches of sub-metric size leading to the almost complete disappearance of some ridges.

Most of these gaps were open after the flood of the fall of 2011 (Hamdaoui, 2012). However, exceptions must be made when we find benches having largely overestimated spacing but are weakly affected by the opening of the breaches. This stability owes to the firm texture of the soil and a good adaptation of the underlying bedrock.

Installation of the Benches Without Taking into Consideration the Mineralogical and Geotechnical Specificities of the Clays: Benches do not hold well when they are predominantly prevailed with Smectite or Vermiculite clays; even with annual monitoring and maintenance, since soil texture is largely influenced by the mineralogical spectrum of the underlying bedrock core. Smectite and Vermiculite clays have limited plasticity and consistency and are subject to considerable erosion (Azaiez, 2016). They have an important interlayer spacing, thus causing a fast exchange with rainwater which causes destabilisation and creep of sheets. These clays are widespread in both watersheds, especially in the Souar corridor (Azaiez, 2020 and 2021).

The State intervention in terms of setting up benches in the Souar corridor and the Northeastern part of the El Mssine wadi watershed did not consider the geotechnical characteristics and the swelling-shrinkage capacity of these clays (Azaiez, 2016 and 2021).

It must always be clarified that on other clay slopes, the old benches dating back to the sixties are still functional and remain safe from opening breaches, although the slope is considerable.

Two facts come into play, first Kaolin clays are very consistent and firm and their interlayer spacing is narrow. These are the clays of the Cretaceous period and especially those of the Jurassic period that are far from being clays of alterities, which show well-stacked sheets which prevent the exchanges with water. The second fact is related to a highly underestimated inter-bench spacing at the distance defined by the Bugeat formula. This type of bench is only found in the upstream part of Wadi El Hadada.

Badly sized benches on a substrate rich in gypsum: The immensely damaged benches in the two watersheds are the ones set up on slopes that contain a lot of gypsum. With the dissolution of this element, there will be a call to the void, and consequently the formation of the suffocation holes and tunnels, which transform themselves very quickly into real ravines in ex nihilo. The situation has become irremediable in the northeastern part of the sub-watershed El Mssine.

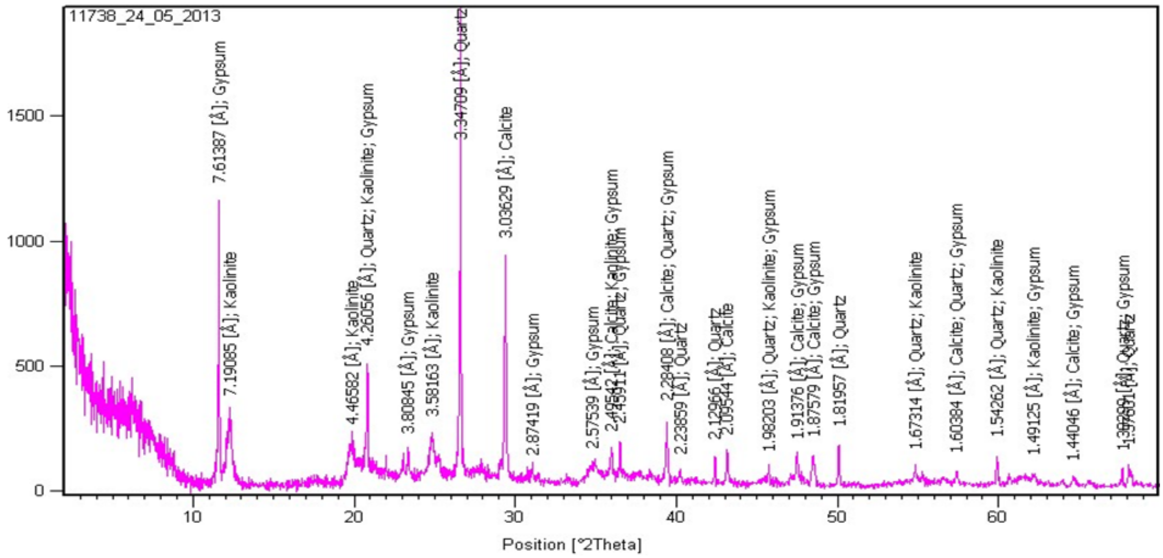
Even the implementation of lentisque does not have a beneficial effect. The slopes are much more destabilised in the Souar corridor as far as the soft parent rock (Souar’s clay-marly formation) shows a high concentration of gypsum (Figures 9 and 10). In such areas, it would not be advisable to make bench terraces in silty gypsum soil and should not be constructed on slopes over (25 per cent and 30 per cent) (Nasri, 2002; Azaiez, 2016).

The Lack of Follow-up by Both the State and the Farmer: The maintenance of the works that are already in place is an easy task to do but it is rarely taken care of by the beneficiaries. The forms of failure reported by location demonstrate that the erosion control policy was not designed as part of a participatory, multidisciplinary, and relevant approach, which considers all components of the natural environment and the socio-economic conditions of the peasants. For example, the benches, dry-stone curb arrangements and the nine hillside reservoirs undertaken in El Ogla watershed have been programmed to protect the hilly dam located further downstream whose life span has been estimated at 28 years.

However, seasonal, and annual measures show an ever-faster rate of siltation, to the point that it will be silted in its entirety after 17 years. This is mainly related to the predominance of cultivated land but insufficiently protected against erosion. The development of mechanisation, agricultural intensification and the undeniable extension of the cereal fields have been accompanied by an

Figure 9

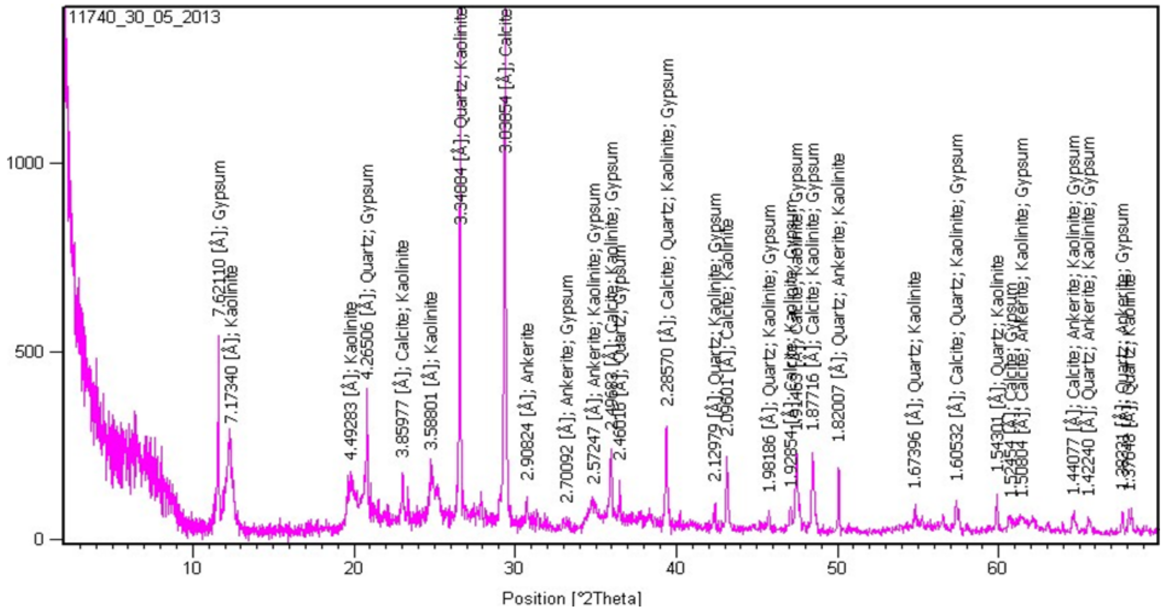
X-Ray Diffraction Patterns (XRD) of Clays Sampled from the Damaged Benches of the El Ogla Basin



Source: Results of XRD analysis, 2014

Figure 10

X-Ray Diffraction Patterns (XRD) of Clays Sampled from the Damaged Benches of El Hadada Basin



Source: Results of XRD analysis, 2014

exacerbated increase in the erosion crisis. This uniformity of the agricultural landscape was responsible for the removal of fine sediments by stripping or gullying (Azaiez, 2016, 2021).

Comparison of the Effect of Benches to the Dry -Stone Cords: In Table 5, a comparison was made between dry-stone benches and cords from the point of view of runoff water storage and sediment trapping capacity. As a result, the study identified the high water and sediment storage capacity of the recent benches constructed as part of the second National Strategy for Water and Soil Conservation. These benches can store a volume of water of 1027 m3/ ha or 2.5 times the capacity of the former benches (Table 5).

Table 5

Water and Sediment Retention Capacity: Comparison Test between Benches and Dry-Stone Cords

Anti-erosive management	Length (m/ha)	Retention capacity			
		Water retention capacity (m^3)		Sediment retention capacity	
		Water retention Capacity (m^3/ha)	Specific retention (m^3/ha)	Solid Deposit (m^3/ ha)	Specific deposit (m^3/ha)
Recent benches	163.0 m/ha	95.80	1027.0	20.8	149.4
Old benches	547.7 m/ha	31.27	402.9	78.4	915.3
Dry stone cords	1304.1 m/ha	0.005	1.75	0.4	180.6

Source : Nasri, 2002, DG/ACTA-MARH, 2005, Hamdaoui. M, 2012 and Azaiez, 2016

The old benches, on their part, have a good storage capacity of 400 m3/ha despite their net depreciation. This relatively high capacity is attributed to the density of the benches, nearly 550 m/ha. Then it follows a significant sedimentation rate behind the sides of these benches, in addition to their depreciation. The solid deposits measured in the benches of the sixties are in the order of 915 m3/ha (DG/ACTA-MARH, 2005).

The rate of high solid deposits is justified by the duration of operation of these structures, with more than four decades, thus indicating a specific erosion of nearly 22.5 m3/ha/year. Compared to recently built slopes (in the 1990s), there was a specific erosion rate of nearly 30 m3/ha/year. These results were evidenced by the Cesium137 method applied in El Ogla basin as shown in Table 5.

The specific soil loss estimated by the Cesium 137 method was in the order of 34 t/ha/year (Azaiez, 2016). Nevertheless, all works complement each other and each one assures functionality. For instance, the partial or total retention benches make it possible to store the water, to improve the infiltration and to reduce the harmful effect of the runoff.

While the dry-stone cords do not allow the storage of runoff water, they can in counterpart slow down the speed of flow, delay the time of concentration of water in the outlet, significantly reduce the aggressiveness of floods and reduce siltation of dams to its minimum (DG/ACTA-MARH, 2005; Azaiez, 2016 and 2020).

Often the water retention capacity could have been significantly higher if the bench terraces had been inclined inwards. Since vast number of bench terraces slope outwards and the soil is rich in clay, the water and sediment retention is further reduced.

Table 6

Comparison of Accumulation Rate between Different Structure Management Obtained by Cesium 137

The management benches	Accumulation rate
Dampened benches (old)	0.5-3 t/ha/year
Recent benches	6-7 t/ha/year
Dry stone bounds	4-5 t/ha/year

Source: Nasri, 2002, DG/ACTA-MARH, 2005, and Azaiez, 2016 and 2021

Conclusion

This research based on a qualitative and quantitative evaluation of the behaviour of bench terracing towards the different erosive processes, found that the stability or the degradation of the grounds was not homogeneous everywhere in the two watersheds studied. In places, especially where the slopes are formed by Kaolin clays, the introduction of bench terracing was potentially beneficial for slope improvement that was already covered by a layer of skeletal soil. At the global scale, the specific loss of land of 34/t/ha/year could be considered as a bad sign and a real alert for the State and for the peasants to take things in hand before reaching a critical threshold beyond which the situation becomes irremediable and irreversible.

Erosion, with its multiple aspects, requires the implementation of bench terracing which imposes a real solidarity between the State and local farmers. It is through the implementation of participatory management programmes that are technically feasible and adapted to local specificities that we can deal with the inevitable degradation of land (Azaiez, 2016, 2021). The bench system must be integrated into a new reading of the rural space-based less and less on arable crops, open and conducted in large plots.

When it comes to bench types, a specific distinction must be established between level bench terrace, bench terrace declining outward, and bench terrace sloping inward in relation to types of soil, occupation, and slope value. Knowing that terraced benches are not suited to the area dissected by the gullies, which are marked by slopes of over 30° (Nasri, 1998, 2002), farmers must avoid, as much as possible, benching in areas where there is a risk of landslides.

These suggestions are made to help foresters, CES engineers and hydraulicians (Soil and Water Conservation) in making planning decisions. The key objective is to succeed in setting up a database of digital data (qualitative and quantitative) which could be updated for better monitoring and evaluation of bench terracing in terms of reducing runoff velocity and soil erosion. The current research is not exhaustive, and the results remain to be verified and improved with the choice of other more representative watersheds to test. It is important to clarify where and when bench terraces are particularly appropriate.

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Author Contributions:

Azaiez Naima: Performed the measurements, planning and supervised the work process (collection of experimental data, analysis, drafted the manuscript) and interpreting the results.

Narjes Baazaoui: Assistance in editing and preparing the manuscript.

Besma Sghaier-Hammami: Revision of the manuscript

Ali Hamza: Performed critical revision.

Ilhem Fethi Blel: Worked out the technical details, and the numerical calculations.

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