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CONTRIBUTION TO THE STUDY OF RUNOFF AND EROSION OF LOW SLOPE HOMOGENEOUS HYDROLOGICAL UNITS OF A WATERSHED OF THE MIDDLE VALLEY OF MEDJERDA TUNISIA

CONTRIBUTION À L'ÉTUDE DE RUISSELLEMENT ET ÉROSION DES UNITÉS HYDROLOGIQUES HOMOGÈNES À PENTE FAIBLE D'UN BASSIN VERSANT DE LA MOYENNE VALLÉE DE LA MEDJERDA - TUNISIE

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ABSTRACT

The rainfall simulation tests on homogeneous hydrological units soil samples of a Medjerda middle valley watershed show that the characteristics of the upper surface soil layer and types of management practices as well as the rain characteristics (duration, intensity frequency) control the infiltration-runoff process and determine later the rain aggressiveness degree.

The hydrological responses of the same hydrological unit are different. That was related to the tillage practices types.

The increasing of the intensity of agricultural practices causes intense soil biodegradation (low organic matter content less than 2%) and distracts consequently its structural stability, thus favors rain aggressiveness process. Indeed, a plowed soil exposed to rainfall of intensity of 54 mm / h loses 3.31 g of soil corresponding to 0.13 kg / m^2 of specific erosion whereas soil sample of olive trees the loss is equal to 2.24 g and the specific erosion is about 0.1 Kg / m^2.

Keywords: rainfall simulation, rain aggressiveness, runoff coefficient, runoff, soil.

RESUME

L'essai de simulation de pluie sur des échantillons des sols des unités hydrologiques homogènes d'un bassin versant de la moyenne vallée de la Medjerda montre que les états de surface et les types de préparation de sol ainsi que les caractéristiques de pluie (durée, intensité fréquence) contrôlent le processus infiltration-ruissellement et déterminent l'ampleur l'agressivité de pluie et sa dégrée d'impact.

Les réponses hydrologiques des sols d'une même unité hydrologique sont différentes, ceci est en rapport avec le type de préparation du sol. L'intensité croissante des pratiques agricoles provoque la biodégradation intense du sol (une teneur faible en matière organique moins 2%) et une diminution de sa stabilité structurale augmentant ainsi le pouvoir érosive de pluie soit par effet spash ou par l'érosion en nappe en cas de saturation du sol. En effet, un sol labouré exposé à la pluie d'intensité de 54 mm/h perd 3,31 g de sol avec 0,13 Kg/m^2 comme érosion spécifique alors qu'un sol cultivé en olivier la perte est de 2,24 g et l'érosion spécifique est faible également de 0,1Kg/m^2.

Mots clés: simulation des pluies, agressivité des pluies, coefficient de ruissellement, ruissellement, sol.

INTRODUCTION

Both of climatic, topographic and edaphic factors, inadequate land management methods, the inadequacy between cultivation practices and inappropriate techniques contribute to land degradation.

The agricultural sector in Tunisia is confronted with the problem of water erosion. The environmental risk of soil degradation has been increased. 14 million ha are threatened by the degradation, of which an area of 11.5 million ha is threatened by high degradation. Consequently, 10 000 ha are annually loosed (CNEA, 2008). Generally there are two erosion factors: rain aggressiveness (its kinetic energy (Kinnell, 2005) and runoff energy (Kinnell, 2005). The kinetic energy of the drops is therefore low in comparison with a natural rain and it was of high speed (Uijlenhoet and Stricker, 1999).

Rainfall simulation tests were carried on different soil types under different management practices and land use, namely to investigate:

(i) The effects of different soil management practices on runoff parameters and

(ii) The sediment concentration under different initial soil moisture conditions and characteristics of the upper surface soil layer (i.e. initially dry soil surface) and rainfall intensities in Mejerda middle valley watershed.

MATERIALS AND METHODS

Study area

The study watershed is located between the longitudes 9°36'31.84"E and 9°39'11.42"E and the latitude 36°32'57.15"N, 36°31'27.48"N. It covers an area of 5 km² and of perimeter of 12 km (Fig.1). It is characterized by:

A semi-arid Mediterranean climate with an annual rainfall ranging from 206 mm to 669 mm (DGRE, 2013). Rain is characterized by a short-term regime, high-intensity.

By reference to the soil map of the Mejerda watershed established by Rodier et al (1981), the pedological cover is characterized by the dominance of little developed soils of erosion and vertisolic soils on limestone, calcimorphic soils which are associated with isohumic soils.

The topsoil hydrological criteria are characterized by the dominance of clayey-silty to clayey texture.

Geomorphologically: the zone is characterized by the dominance of (marls, calcareous sandstones, calcareous crusts, pebble). The watershed includes:

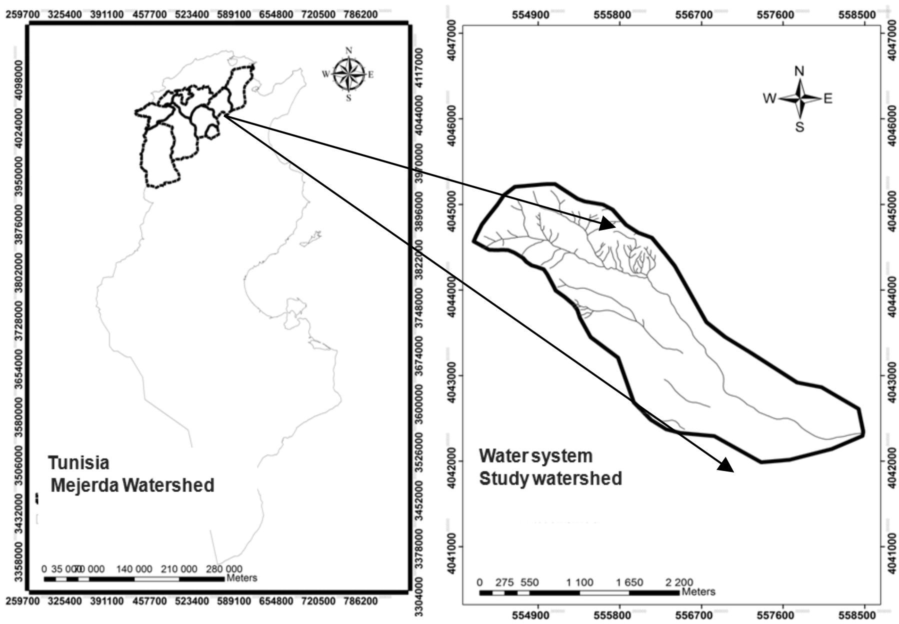

Figure 1: Map of localization of the study watershed

Cereal crops occupy 39% of the total watershed area. (Irrigated area accounted for 67 percent of that total cereal crops area but rainfed area accounted for only 33 percent).

Olive tree-dominated the arboriculture and covers 21% of the total watershed area. Brushwood covers an area of 10% of the total area. The rest of the area (30%) is a bare land.

EXPERIMENTAL DESIGN AND SOIL SAMPLING

The objective of this study is to determine certain hydrodynamic characteristics of soils, on a small scale and under various pedological and rainfall conditions, based on the rainfall simulation which is carried out in the hydraulic laboratory of ESIER. The rainfall simulator used is of the Armfield type. The intensities used are equal to (I_{30}max of the different return periods) which are the results of the statistical study of the Slouguia station (DGRE, 2007) (Table 1). The study area was subdivided into homogeneous hydrological units (Fig.2), by the superposition of:

- Land use map (Fig.2)
- Soil map (Fig.3)
- Slope map (Fig.4)
- Orientation map (Fig.5)
-

Table 1: I_{30} max used

Recurrence (Year)	**Time (minutes)**		
	30		
	BI	Imax	BS
2	25	29	33
5	31	37	42
10	35	42	50
20	38	48	57
50	42	45	66
100	45	59	73

(DGRE, 2007)

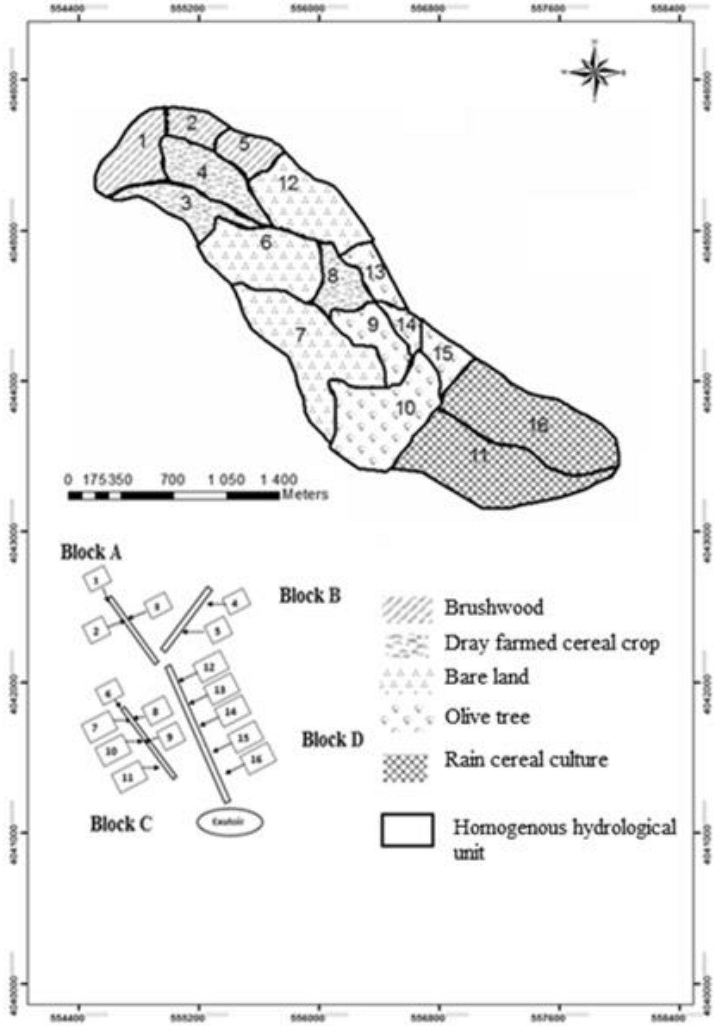

Figure 2: Map of land use and distribution of the homogenous hydrological units in the study watershed

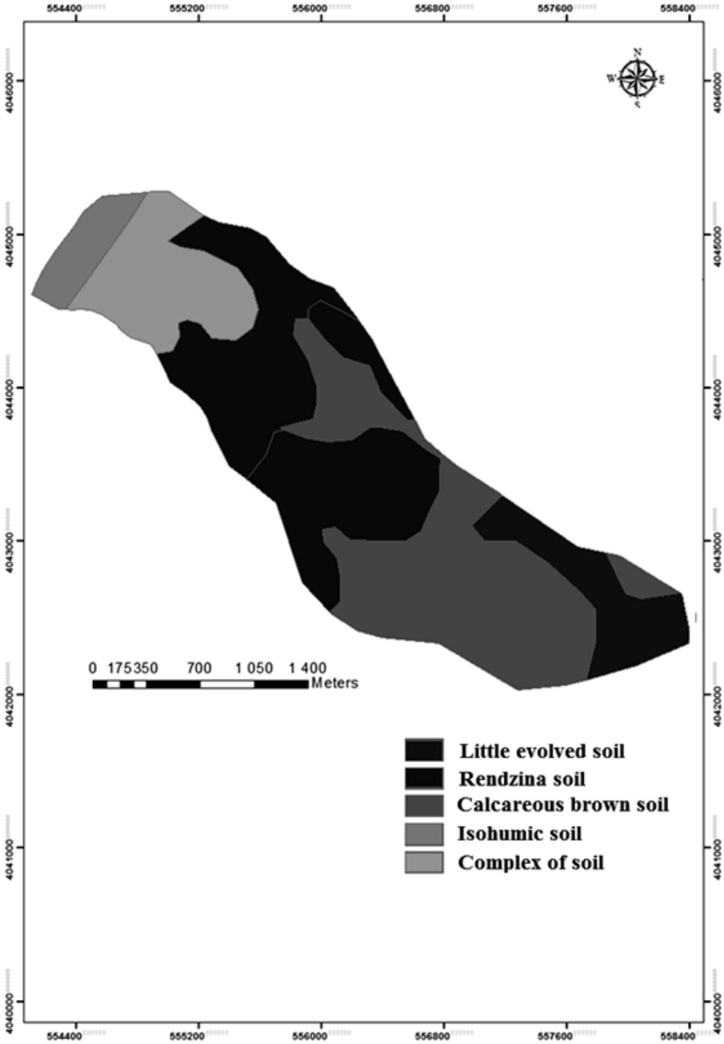

Figure 3: Soil map

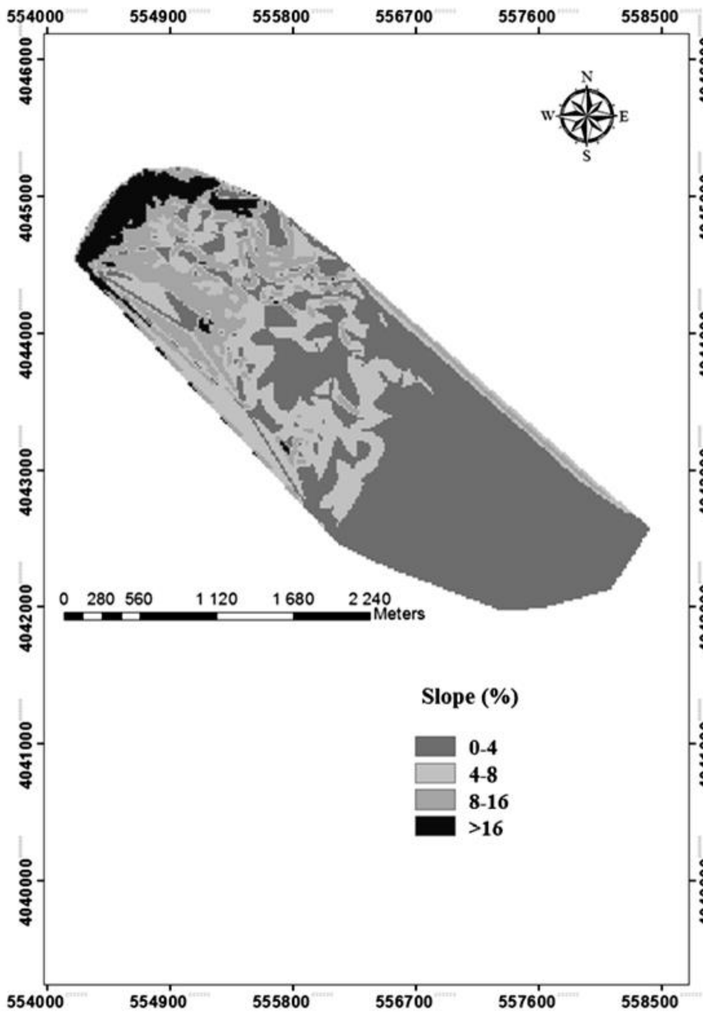

Figure 4: Slope map

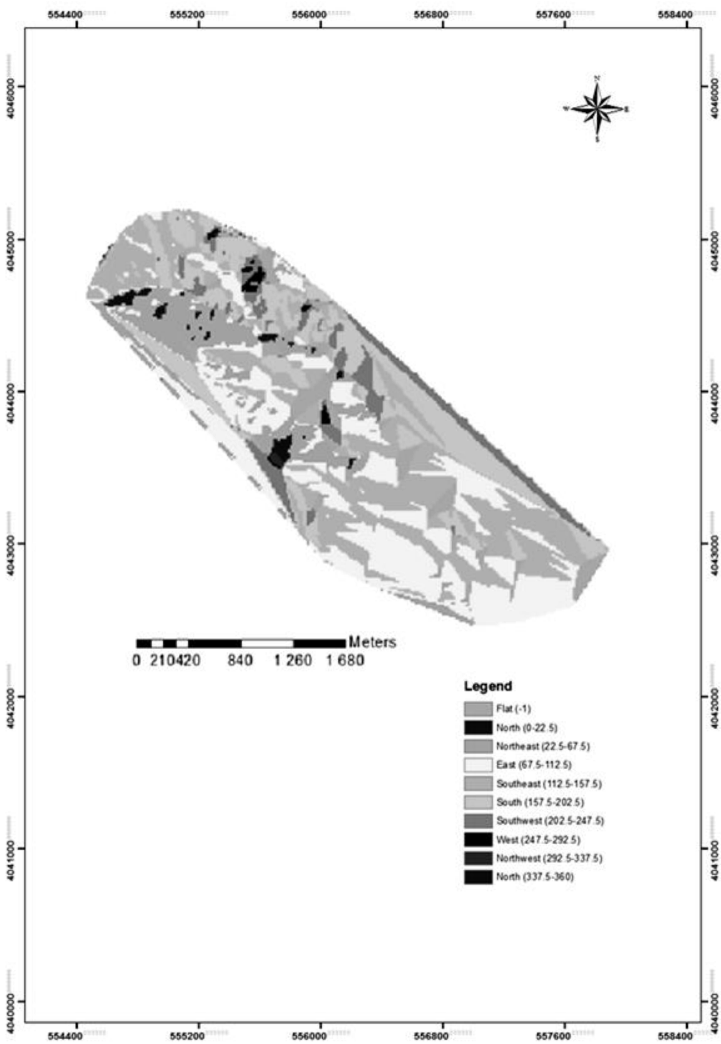

Figure 5: Map of terrain orientation

The slope factor was considered as the main factor of the water erosion process; on the other hand, the slope significantly intervened to explain the soil loss by gullying process. This conclusion is consistent with the works of Poesen (1987) Lal (1988) Hudson (1992), Roose (1981), and De Noni and Viennot (1998) which show that linear erosion depends on the kinetic energy of runoff more than the rainfall energy (origin of sheet erosion) if the slope exceeds 15% (Roose, 1994).

The objective of this study is determine the roles of land use and the characteristics of the upper surface soil layer and types of management practices on water erosion process by an analytical and comparative study of runoff and soil erosion parameters of the few low slope homogeneous hydrological units. Table 2 summarizes the characteristics of each homogeneous hydrological unit studied. Experimentation has focused on the study of two soil types and three type of land-use.

The samples were taken from each homogenous hydrological unit during all soil sampling campaigns at locations covering three morpho-pedological compartments (upstream, intermediate, and downstream) of the slope (Table 3).

Table 2: Characteristics of the studied homogeneous hydrological units

Block	HHU	Soil type	Altitude (m)	Slope (%)	Orientation	Land use
C	7	Rendzines	192-244	3,03-7,47	north-east	Bare land
	10	Brown calcareous	140-192	0-7,47	flat	Olive trees
	11	Brown calcareous	140-192	0-7,47	North-north east	Irrigated culture (Cereal Crops)

Table 3: Characteristics of the studied homogeneous hydrological units soil samples

HHU	Soil sampling site*	OMC (%)	WC (%)	Stoniness (%)	Soil surface characteristics
10	Downstream	2,75	8	55	watercorse
	Upstream 1	0,74	14	54	Plowed
	Upstream 2	0,53	6	73	Agricultural tack
7	Middle	1,1	7	78	Bare land
11	Upstream	0,74	9	86	Natural vegetation
	Middle	0,84	9	68	Plowed

OMC: Organic matter content ,WC: Water content , HHU: homogeneous hydrological units

* The disposition throughout the watercourse and the runoff sense and direction

Textural characteristics and structural samples of the soil samples are summarized in Table 4.

Soil samples are putted in experimental plots after its sieving at 5mm.A rainfall intensity calibration by the variation of (the debit, the speed of the motor, the level of rain gauge in the tray simulator) and slope adjustment at 2.5°, 5° are realized. The rainfall simulator aperture disc is equal to 15°.

Numerated recipients are putted in the experimental plot downhill to receive and collect runoff .Runoff samples are taken after 10, 20, 30, 50 and 60 min. Sediment concentration was determined gravimetrically on the runoff samples after oven-drying (at 105 °C). We focused particularly on runoff and erosion parameters (e.g., runoff tripping time, runoff volume, specific erosion) at different temporal scales of measurement.

Table 4: Soil characteristics

HHU	SSS	Soil characteristics					Texture
		Clay	Fine Silt	Coarse silt	Fine Sand	Coarse Sand	
	Downstream	47	31	41	6	6	Silt
10	Upstream 1	43	30	11	9	7	Clay silt
	Upstream 2	44	22	13	15	6	Clay
7	Middle	37	30	13	9	7	Silty Loam
	Upstream	39	35	8	15	3	Silty Loam
11	Middle	42	22	15	15	6	Clay

SSS: Soil sampling site

The experimental approach focuses on the:

- Study of the impacts of soil and surface conditions on the hydrological responses of the hydrological units studied by monitoring of runoff parameters.
- Assessment of environmental risks of soil physical degradation: water erosion indicative of soil vulnerability to degradation.

Influences of soil and surface condition on the hydrological responses of hydrological units

The runoff begins less rapidly for the case of the upstream 1 than the upstream 2 of the same hydrological unit number 10 ,that was related to the initial moisture condition which were respectively 6% and 14%. Arabi and Roose (1993) have shown that the runoff limit varies from 18 to 20 min on dry soil, to 30 min on wet and slaked soil. Luk (1985) and found that runoff an soil lose are function of the antecedent moisture content. That was verified in clay soil by Mamedov et al. (2002) but this effects was negligible in silt Loam soil.

Runoff begins after 30 min for the case of soil sample which was taken from the middle of the irrigated perimeter compared to the soil sample of the same hydrological unit but taken from the proximity of the agricultural track which is compacted with (stoniness of 86%, soil organic matter content = 0.74 %, initial soil moisture conditions = 9%). Drissa et al (2004) show that runoff is mainly related to aggregation in dry years, but that in wet year the and soil organic carbon must also be taken in consideration. Barthès et al (2002) show that if the rainfall duration increases, runoff becomes less dependent on aggregation and became more related to the carbon content. The authors have shown that macro-aggregate stability is related to soil organic matter content and can be used as an indicator of its vulnerability to degradation and water erosion (Al Karkouri et al., 2000; Tisdall, 1982; Barthes, 1999) but Cogo et al (1984) found that the effect of standing stubble on soil erosion reduction is better than surface roughness effects. For that reason it was concluded by (Mostaghimi et al.1998) that the retention of wheat stubble in situ without incorporation (standing stubble in furrows) can be used a means of soil water erosion reduction.

The soil surface characteristics and the types of land use are determinants of runoff and infiltration processes, since runoff begins only after 8 min for the case of soil sample of bare land belonging to the seventh hydrological unit and after 30 min for the case of land cultivated with olive tree under a rainfall intensity of 60 mm / h during one hour.

Vegetation cover and soil surface characteristics are considered as important parameters of runoff process (Sud YC, 1996).For that reason, as it was concluded by (Kosmas et al. 1997) that the exponentially decrease of runoff parameter is correlated with the vegetation cover .For that reason in conservational tillage and in order to prevent surface wash erosion and overland flow, it was essential to maintain a crop residue cover and standing stubble. That was verified on silt loam soil by Mostaghimi et al. (1988). The rainfall intensity increases is accompanied by a shortening of runoff tripping time ,indeed for the soil sample of the hydrological unit 11, runoff tripping time is reduced from 30 min to 18 min by the increase of the intensity from 48 to 60mm / h. (FIGS. 6 and 7).

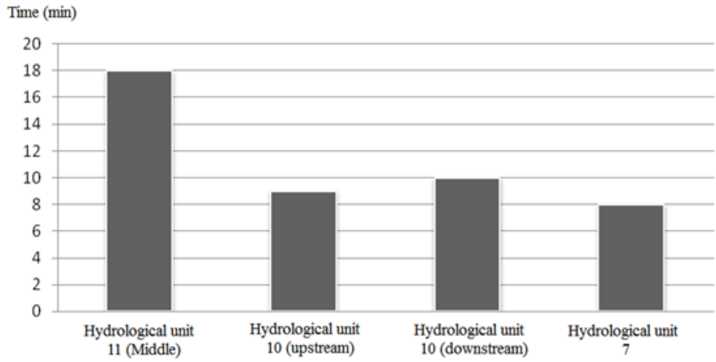

Figure 6: Runoff tripping time under rainfall intensity of 48 mm/h for all hydrological units

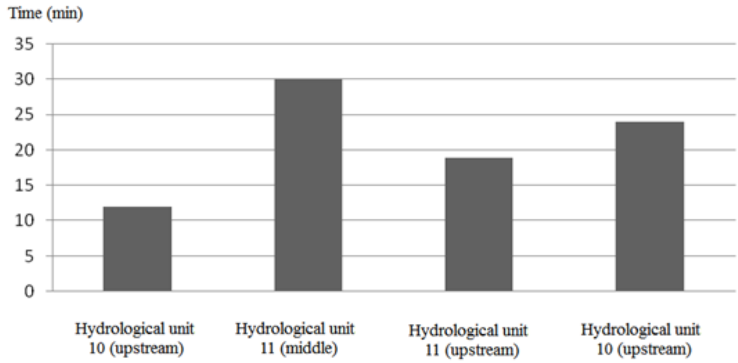

Figure 7: Runoff tripping time under rainfall intensity of 60 mm/h for all hydrological units

Soil samples of limestone brown soil from the irrigated perimeter of unit number 11 (medium) and (upstream) have more runoff capability than the soil sample of the hydrological unit number 10 (upstream 1) with runoff coefficients respectively of 18,7 and 25.92% and 11.11% under rainfall intensity of 48 mm/h during one hour. The authors have shown that the production of runoff is mainly related to the physical characteristics of the topsoil layer and its vegetation cover (Barnett, 1966; Sabir, 1994).

Yair and kossovsky (2002) have shown that the runoff genesis in the semi-arid regions is controlled by soil surface characteristics rather than by the rainfalls quantity. The cumulative runoff lamina increases from 0.93 mm to 6.44 for the soil sample of the hydrological unit 7 and from 2.13 to 8.13 mm for the case of the unit 10 by the intensity increasing from 36 to 48 mm / h.

By reference to the figures (8,9,11), the calcareous brown soil sample of the downstream of the hydrological unit 10 which is plowed cultivated with olive tree produced the respective cumulative runoff lamina of 2.13 / 8.13 / 12.86 mm corresponding to the respective runoff coefficients 5.91 / 16.94 / 21.42%, while, the soil sample taken from the rendzines of the hydrological unit 7 of bare land has a runoff coefficient of 2.58 / 13.42 / 22.22% relative to cumulative runoff lamina quantity respectively of 0.93 / 6.44 / 13.33 mm) under the rainfall intensities 36/48/60 mm/h .

Under a rainfall intensity of 48 mm/h, the calcareous brown soil sample taken from the downstream of the hydrological unit 10 which is plowed has a runoff coefficient of 16.94% which corresponds to 8.13 mm of cumulative runoff lamina, on the other hand, the soil sample taken even from the hydrological unit but from an agricultural track has a runoff coefficient of 37.12% which corresponds to a 17.82 mm of cumulative runoff lamina.

That may be related to the soil physicochemical characteristic mainly the organic matter content, in fact the soil sample of the downstream has 2.75% as organic matter content while the sample of the upstream has only 0.53% which will be transported continuously by runoff process.

The runoff begins mostly at the time interval of 40-50 min under the rainfall intensity of 36 mm/h. If the rainfall intensity increased to 60 mm/h the runoff begins at the time interval of 10-20 min. In the study of (K. Jin et al., 2008) "Generally, three distinct stages in the runoff process are distinguished. In stage I, defined as the period from the start of rainfall to the time to runoff initiation (Ti), all rainfall infiltrated and no runoff occurred. Stage II represented the period in which infiltration rapidly declined and runoff started at the same time and increased rapidly. Stage III started with a constant discharge rate (Dc) indicating a constant rate of infiltration". For this study we distinct only the first stages I and II and the start of stage III, (there was not a constant rate of infiltration).

The hydrological responses of soil samples taken from the upstream of the hydrological unit 10 but from different the soil surface characteristics are different. Indeed, under a rainfall intensity of 48 mm/h the soil sample of agricultural track with an organic matter content of 0.53% and a water content of 6% produces a 17.82 mm of cumulative runoff lamina which correspond to runoff coefficient of 37.12% while a soil sample taken of the same hydrological unit but of plowed land produces a 5.33 mm of cumulative runoff lamina which correspond to runoff coefficient of 11.11% (Figure 9).

Similarly, the comparative study of runoff parameters of the soil samples taken from the irrigated perimeter of the hydrological unit 11 but of different surface conditions show that the runoff is more important in the upstream sample near the agricultural track with a runoff coefficient of 25.92 % corresponding to cumulative runoff lamina of 12.44 mm while the soil sample of the medium which is plowed have a runoff coefficient of 18.7% and a cumulative runoff lamina of 8.97 mm under a rainfall intensity of 48mm/h during one hour.

This can be related to the plowing effect which reduces runoff by improving infiltration process. That was demonstrated by (Bahri et al). Plowing before rainfall on dry soil increases the infiltration. The plowing increases the infiltration by 97% compared to no plowed soil, the superficial plowing by poly disques perpendicularly to the slope increases it to 65% while plowing affected in the direction of the slope increases it to 44%.

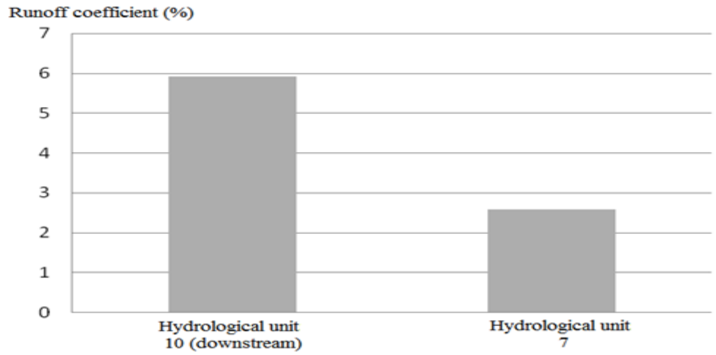

Figure 8: Variability of runoff coefficient under rainfall intensity of 36 mm/h for hydrological units 7 and 10

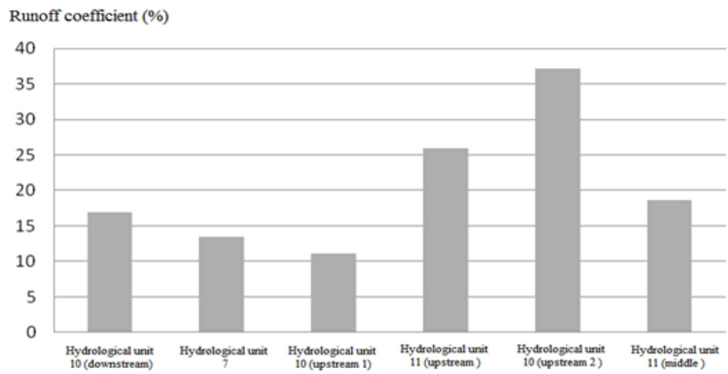

Figure 9: Variability of runoff coefficient under rainfall intensity of 48 mm/h for all hydrological units

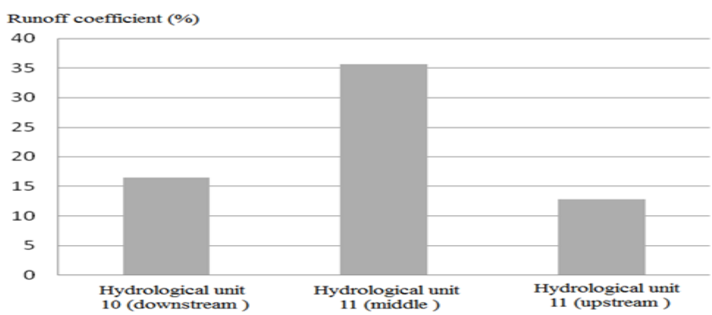

Figure 10: Variability of runoff coefficient under rainfall intensity of 54 mm/h for all hydrological units

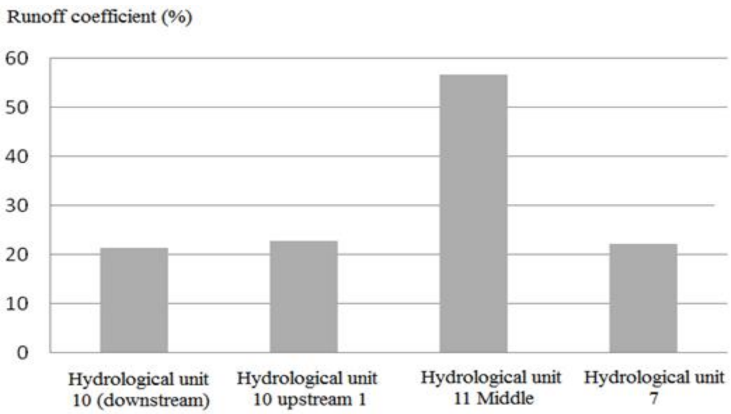

Figure 11: Variability of runoff coefficient under rainfall intensity of 60 mm/h for all hydrological units

Assessment of the environmental risk of soil physical degradation: *Water erosion indicator of soil vulnerability to degradation*

Exposed to simulated rainfall intensity of 60 mm / h during one hour ,the plowed soil loses 3 g of soil which correspond to specific erosion of 0.13 kg/m^2 of whereas a samples of olive tree the soil lose is about is 1 g and the specific erosion is also low ant it was about 0.044 kg /m^2 (Fig. 12).

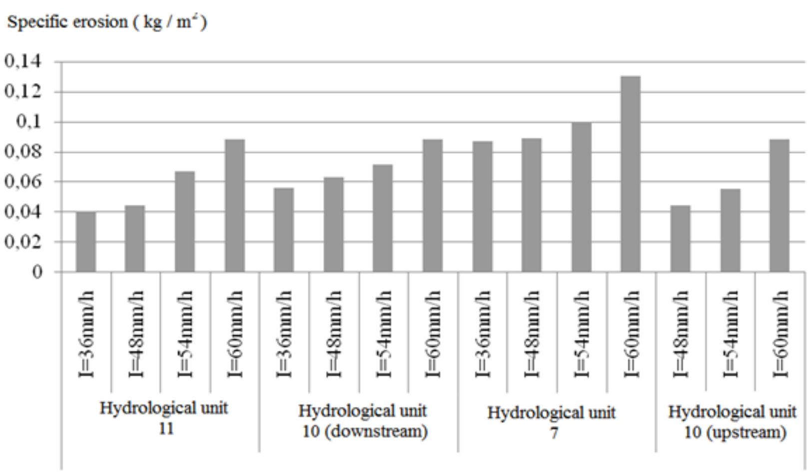

Figure 12: Variability of specific erosion under all rainfall intensities of 48 mm/h for all studied hydrological units

Plowing in the direction of the slope can multiply runoff and soil losses by five (Chaker et al., 1996), in addition the increase of runoff and erosion is related to the increasing intensity of cultivation practices as it was reported by different authors (West et al., 1991, Bradford et al., 1994) and (Roose, 1983; 1994).It was the sheet erosion that occurs: this form of erosion is particularly harmful to agricultural land because it attacks topsoil humus.

If the intensity is increased to 60 mm/h, the loss will be 0.088 kg/m^2 for the units 11 and 10, while the hydrological unit 7 of the bare soil has a maximum erosion value of 0.13 kg/m^2.

CONCLUSIONS

This paper focuses on the effect of two soil types (rendzines and calcareous browns soils) and three land use type (bare soil, olive tree, irrigated crop PPI) on the hydrological responses of the surface horizon (0-10cm) in term of erosion and runoff process. Indeed, the consideration of slope factor as characteristic of erosion was evaluated in this study by the comparison of runoff and erosion parameters of soil samples of low slope homogeneous hydrological units.

Runoff parameters are function of soil surface characteristics which were related to land use, indeed, under a rainfall intensity of 36 mm/h after 45 minutes of rainfall, the runoff is more important for the soil sample of the hydrological unit 7 of bare land (ravine) than for the hydrological unit number 10 (olive tree): the maximum values registered are 1.33 and 0.53 mm respectively. The terrain topography (slope, orientation) determines the soil initial moisture state, which influences its hydrological response. Runoff begins less rapidly in the soil sample of upstream of the unit 10 than the downstream. This is related to the initial moisture content which is of 6% and 14%, respectively. The use of rainfall simulation is an effective way to predict soil degradation by water erosion, which is the result of interactive change between land use, soil surface characteristics and climate.

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