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Original article

# Estimation of Runoff and Sediment Transport: Case of the Mounts of Beni Chougrane, Mascara, Algeria

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**Abstract**

The estimation of runoff and sediment transport in mountainous areas, using the rain simulation method among others, allows us to control the effect of water erosion on the considerable loss of arable land share and siltation of the other dams. The objective of this study is to quantify runoff and sediment transport and finding mathematical models explaining the relationship between the runoff coefficient "Kr" and sediment concentration "C".

The rainfall simulator used in our experiment is a "ORSTOM". We chose the parameters according to the conditions observed in the field, namely rain intensity (I1 = 30, I2 = 50 and I3 = 80 mm.h-1), ground slope (P1= 12.5 and P2 = 25%) and soil moisture state (S: Dry, H: damp TH: very humid). These settings are applied to marl representing a high percentage in the mountains of Beni Chougrane in western Algeria.

The results show that there is significant variations in Kr and C. The search for mathematical models explaining these relationships led us to choose the linear model which best explains the relationship between C and Kr in %: C = A + BKr , with a correlation coefficient of 85%. The logarithmic model LogC = A + B.LogKr, ranks second with a correlation coefficient of up to 75%. The runoff coefficient is closely related to the intensity of the rain "I" and "P" slope whereas the sediment concentration varies in proportion to the intensity of the rain and the moisture condition of the soil "H". The application of the technique of rainfall simulation which has the advantage of controlling parameters considered, allowed us to establish a more realistic modeling to explain all the fluctuations of these two parameters.

**Keywords:** Soil erosion, Rain simulation, Runoff, Sediment transport.

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## INTRODUCTION

Most runoff measurement methods and soil infiltration highlighted the need to find new closer to natural conditions techniques, while avoiding the chance and the vagaries of the latter. It is obvious to adequately study the phenomena induced by the rain, the ideal would be to modify or vary to highlight the role of each, while avoiding the chance and the vagaries of nature (Roose, 1994; Hassan et al., 2015)

The rain simulation is a method that provides in a relatively short time many data measured on surface water behavior and soil under artificial rain made and controlled using an apparatus called rainfall simulator.

The mountains of Beni-Chougrane are a good example for the study of water erosion phenomenon.

### Material and Methods

#### *Characteristics of the study area*

The mountains of Beni Chougrane are in the Algerian Northwest. They are one of the major mountains of the western Oran tell, with an area of 2860 $km^2$ (BNEDER, 1982). These mountains are located between the bottom chambers (the plain of La Habra North and the South Ghriss). They present themselves as a well individualized region, a mountainous part of the Southwest facing North-East. The watershed of Oued Fergoug, the object of our study is an integral mountain of Beni-Chougrane (Figure 1).

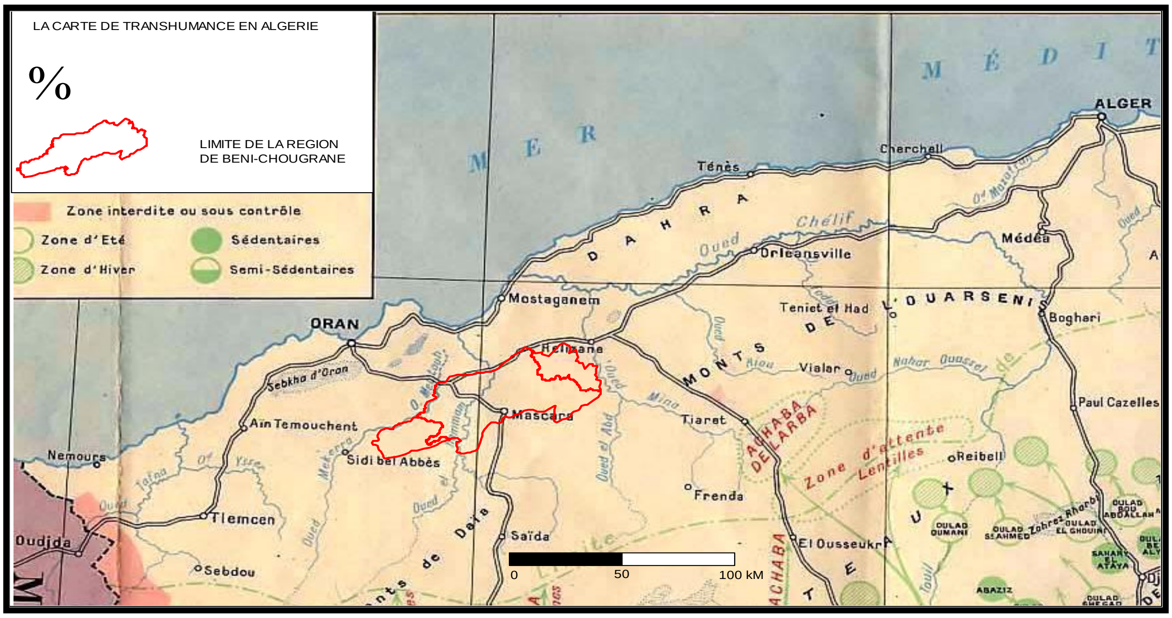


**Figure 1.** Location map of the mountains of Beni-Chougrane, Mascara

***Rainfall***

The average annual rainfall is of the order of 428.3 mm for the Ain Farès station and 281.5 mm for the Bouhanifia station. Rainfall is concentrated during the cold season. It should be noted, however, that the rainiest season is between October to December and the wettest months are December with an average of 60 mm/h and January with 50 mm/h.

***Frequency and intensity of rainfall***

Torrential falls occur during the months of heavy rainfall from late November to February, but they can also intervene during other months, especially in September or October, especially in April and May. The balance of the registered rain in our area shows that there is a remarkable variation in the intensities of the rainfall that can range from minimum values of 2 to 6 mm/h in the drier months (June, July and August), and maximum values of 50 to 90 mm/h in the rainiest months (December and January). The duration of high intensity rainfall is 5 to 10 minutes (Table 1).

**Table 1.** Intensity and duration of rainfall of Mascara region (1991-2016)

| **Month** | **Sep** | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Intensity (mm/h) | 80 | 73 | 60 | 65 | 70 | 40 | 28 | 20 | 04 | 02 | 02 | 00 |
| Duration (min) | 08 | 06 | 10 | 09 | 10 | 07 | 05 | 05 | 03 | 05 | 03 | 00 |

***Temperature***

The average monthly temperatures recorded on a series of 26 years (1991-2016) at the region highlight the existence of two distinct seasons:

- A cold season 6 months from November to April. January is the coldest with an absolute minimum temperature of 3°C.

- A hot season that lasts six months between May and October. August is the hottest with an absolute maximum temperature of 41°C.

During the cold season, the soils of the Beni-Chougrane region are more exposed to erosion phenomenon given the importance of rains. Moreover, during the dry season, the soil is drier and promotes intense erosion if there is heavy rain in a fairly short time.

**Soil**

In this area, there are often young and poorly developed soils, still bound to the rock and having mostly the properties of the latter, mainly furniture marl rocks are the most common distance. From the soils formed on marl and sandstone, the most important are: brown limestone soils and red soils. Throughout this set, erosion is strong enough, rill, gully and sometimes in the form of landslide. Unstable loamy brown soils (1.3 <Is <1.9) are more susceptible to erosion, against vertic soils that cover large areas are more stable (Is = 1), but remain sensitive to erosion due to their very special hydrodynamic behavior. When cracked, too high infiltration causes internal erosion and may even cause landslides later. A more or less saturated state low infiltration easily triggers runoff (Morsli, 1996).

These soils have great potential despite the presence of some deficiencies in nitrogen and phosphorus. If these soils have agronomic benefits, and explain to other factors human fixation in the mountains, are directly subject to erosion (Table 2).

**Table 2.** Soil characteristics of Beni-Chougrane mountains (Laboratory of Soil Science, University of Mascara, 2016)

| Characteristic | Soil A | Soil B |
|---|---|---|
| Clays (%) | 60.2 | 33.5 |
| Fine silt (%) | 22.1 | 4.3 |
| Coarse silt (%) | 7.5 | 21.2 |
| Fine sand (%) | 5.5 | 36.1 |
| Coarse sand (%) | 3.1 | 4.2 |
| Organic matter (%) | 1.7 | 1.9 |
| Instability index | 0.48 | 1.2 |

***Topography***

The mountains of Beni-Chougrane are characterized by extremely confusing topography where the vertices massive domes mingle high plateaus surfaces and deep valleys. Their altitude amount generally from Southwest to South is 300 to 800 meters.

The slope map made from the Digital Terrain Model (DTM), with a resolution of 30 meters, has led us to divide the slopes into four distinct classes (Table 3). The percentage of the dominant slope (00-25%) represents 64.69% of the total area of the watershed (Figure 2).

**Table 3.** Area and slope classes

| N° | Slope classes (%) | Characteristic of the slope | Area (ha) | (%) total area |
|---|---|---|---|---|
| 1 | >50 | very strong | 2474.168 | 20.30 |
| 2 | 25-50 | strong | 1829.429 | 15.01 |
| 3 | 12.5-25 | middle | 3195.694 | 26.22 |
| 4 | 00-12.5 | low | 4688.724 | 38.47 |

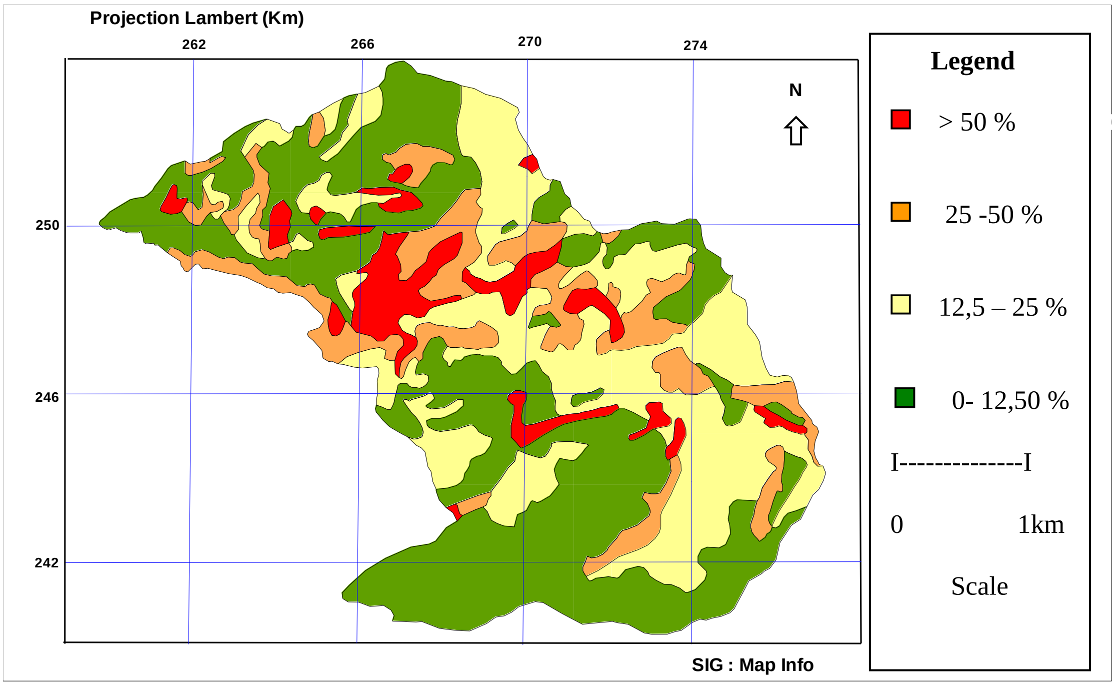


**Figure 2.** Map slopes of the watershed of Oued Fergoug

***Floor sensitivity to water erosion***

By crossing three maps: topographic, lithologic and land occupation, we have achieved a sensitivity map of soil erosion (Table 4; Figure 3), which includes three main classes. 30% of soils are highly sensitive to water erosion, these areas require adequate erosion control strategies to reduce this alarming percentage.

**Table 4.** Degree of sensitivity to water erosion and soil surfaces

| Sensitivity | Area (ha) | (%) total area |
|---|---|---|
| Strong | 3616.18 | 29.67 |
| Middle | 7719.88 | 63.34 |
| Low | 851.94 | 06.99 |

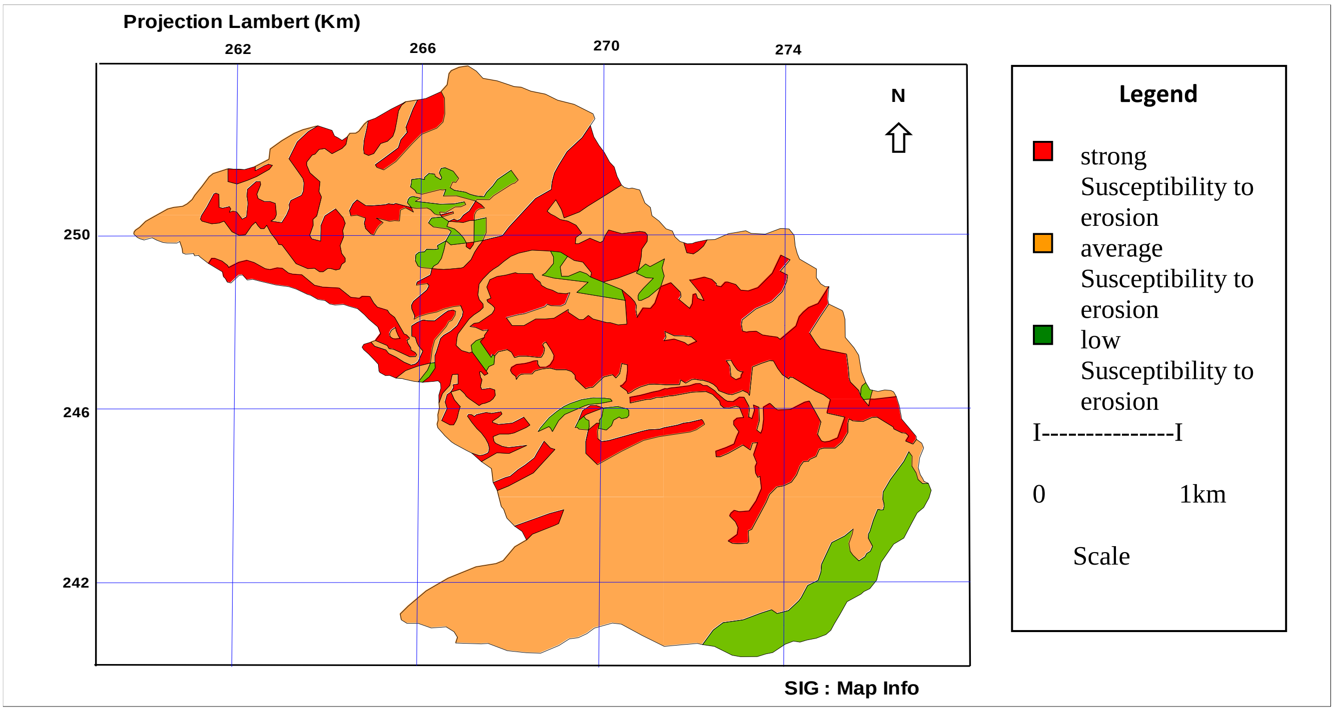


**Figure 3.** Map of soil sensitivity to erosion in the watershed of Oued Fergoug

**Methodology**

Our contribution will focus on the evaluation of runoff and sediment transport using rainfall simulator, based on certain causal factors: moisture condition, the slope of the soil and rainfall intensity (Figure 4).

The results found in the rain simulation performed according to the different states studied, show that there are relationships between sediment load "C" and the runoff coefficient "Kr" and to specify this relationship mathematically, we proceeded to treatment data in order to find the most significant mathematical model between these two parameters. Both mathematical models that gave us satisfactory results are:

- The linear model: Y = A + C = A + B.x B.Kr

- The logarithmic model: Y = A + = A + B.log.x LogC B.LogKr

| Plots | Rain intensity (mm/h) | Slopes (%) | States soil moisture (%) | | | Number of repetitions |
|---|---|---|---|---|---|---|
| | | | Dry | Humid | Very humid | |
| 1 | 30 | 12.5 | 00 | 28 | 34 | 10 |
| 2 | 50 | | 00 | 30 | 32 | 10 |
| 3 | 80 | | 00 | 29 | 34 | 10 |
| 4 | 30 | 25.0 | 00 | 30 | 35 | 10 |
| 5 | 50 | | 00 | 29 | 33 | 10 |
| 6 | 80 | | 00 | 28 | 34 | 10 |

**Figure 4.** Experimental protocol

***Description of the rainfall simulator***

The apparatus consists of a sprinkler system attached to the top of a tower in the shape of a truncated pyramid of 3.8 meters and 16 square meters at the base may receive a tarp for protection against the wind. This structure is supported by four telescopic legs in order to be properly positioned on any surface and particularly on steep slopes.

The rainfall simulator we used is ORSTOM type. Mini rainfall simulators, model ORSTOM, were developed to simulate rainfall intensities of predetermined (known and settled). The floor surface on which the simulator is placed is 4 $m^2$. In the center, delineating a plot of one square meter. This plot has in its lower part a water recovery system that is not infiltrated the output of the plot by gravity: it is the runoff.

The amount and intensity of runoff are measured intermittently by performing taken every minute with a test tube. By knowing the intensity of the rain and the runoff, it can be deduced from the difference infiltration of water into the ground at all times. The nozzle is supplied with water at constant pressure, produces a flat stream of water in a fan shape, the nozzle positioned at 3.7 meters in height was subjected to a balance of movement. The irrigation flow was always constant, and as we increase the irrigated area, the central plot received less water and vice versa.

***Selection of parameters***

- *The intensities of rainfall***:** To determine the intensities and durations with which it must work, we studied the nature of natural rainfall, their height, their intensities and durations. We took into consideration the data recorded at the Ain Fares station for the past five years (see Table 1).

- Analysis of rainfall and the type of rainfall simulator have led us to choose intensities of 30, 50 and 80 mm/h.

The soil moisture states: we applied rainfall events over three soil moisture conditions as follows:

- *Dry condition:* we consider dry soils that have not received rain for 25 days or more; rain simulation campaigns were carried out when the soil was very dry.

- *Wet state:* it is a soil with poor rainfall of about 10 mm/h$^{-1}$ and 24 hours must have passed after the last rain.

-*State Very wet*: it is a floor having recently received more rain, the last of which occurred more than an hour before. In our case the simulated rain is applied after 15 minutes of the previous rain.

*Slope:* The slope is involved in the phenomenon of erosion and runoff because of its inclination, length and shape. Slope classes of 00-12.5% and 12.5-25% account for over 60% of the total area of the watershed (Table No. 02). These data with certain constraints led us to choose two slopes namely 12.5 and 25%.

***Measured parameters***

The usual procedure is to place a container on the plot sheet 1 m$^2$ for a 100% runoff. After we proceeded to set the rainfall intensities chosen in our protocol (30, 50 and 80 mm/h) at each repetition, we must maintain the same height of the nozzle and the same center of gravity on the plot. Measurements are divided into two stages:

- Water the soil surface: rainfall and runoff;

- Solid expenses: concentrations.

Of runoff water samples were taken at the outlet of the plot and to measure stream volumes and quantify sediment load (concentrations), we applied the experimental protocol below (Figure 5).

## Results and Discussion

***Concentrations***

Analysis of the results found on the concentrations measured in grams per liter (g/l) shows that on dry land, the values are higher, they take values in the range from 38 to 54 g/l as the particles are likely to transport the stream water slides. For wet soil concentrations vary between 30 to 100g/l, also for very wet soils such concentrations are more or less moderate values of the order of 26-90 g/l.

The state of a dry soil results in a very dense network of cracks and a complete disintegration into fine particles in the surface horizon. Small disintegrated particles that peel easily are immediately washed away by runoff. For wet against the previous rains have already attacked the earthy aggregates, causing a decrease in roughness, clogging of pores and formation of a surface crust that reduced relative soil removal while generating runoff.

We noticed during heavy rain (80 mm/h), the concentrations are very high in the wet on dry ground. During these heavy rains, when runoff has increased, some runoff nets grew claws and rill which resulted in development of a rill erosion, so a shear runoff and consequently an increase in sediment his increase of sediment may be also due to the energy of the drops of the first rain. This is confirmed by many authors who have shown the role of rain (Smith and Wischmeir, 1978; Henensal, 1986 and Keith Cooley, 1980). The energy of precipitated drops disaggregates fine soil particles which can then be driven by runoff based on its transport capacity. This mechanism starts with the sheet runoff (Ellison, 1945), but very quickly especially in the case of relatively steep slopes, swales are created and gullies where the role of erosive runoff can become very large (Roose, 1998; Ouvry, 2012). Moreover, soil structure is changing rapidly under the action of rain, the nature and intensity of these changes depend on many factors and conditions (Boiffin, 1984; Le Bissonnais 1988; Meddi et al., 2009).

The slope of the effect was observed in going from 12.5% to 25%, the concentration values were two to three times greater. A small slope can promote the accumulation of binding soil particles in runoff force, against a steeper slope creates a rich run-off blade maximum charge of soil particles.

According to the work of authors such as Palmer (1964) and Moss (1983), the particle detachment by rainfall decreases as soon as the rain intensity and degree of the slope are lower, due to a thickening of the streaming water slide, which is protecting the soil from the impact of the raindrops (Ferrera, 1985; Kinnell and Singer, 1990; Mabit et al., 2002). So the concentration is proportional to the intensity of the rain and degree the slope (Table 5).

**Table 5.** Summary table of the different results

| | | | | | | |
|---|---|---|---|---|---|---|
| Int (mm/h) | 30 | | | | | |
| Slope (%) | 12.5 | | | 25 | | |
| States soil | D | H | VH | D | H | VH |
| Cm (g/l) | 38.25 | 29.40 | 26.80 | 42.35 | 30.80 | 28.50 |
| Kr (%) | 14.42 | 61.15 | 68.77 | 18.67 | 64.00 | 70.50 |
| Kr max (%) | 77.93 | 85.13 | 86.33 | 78.03 | 85.60 | 86.36 |
| Int (mm/h) | 50 | | | | | |
| Slope (%) | 12.5 | | | 25 | | |
| States soil | D | H | VH | D | H | VH |
| Cm (g/l) | 39.17 | 38.69 | 32.66 | 47.68 | 37.04 | 36.89 |
| Kr (%) | 28.38 | 70.04 | 74.10 | 34.11 | 72.14 | 78.77 |
| Kr max (%) | 88.00 | 90.40 | 96.00 | 82.00 | 88.00 | 89.00 |
| Int (mm/h) | 80 | | | | | |
| Slope (%) | 12.5 | | | 25 | | |
| States soil | D | H | VH | D | H | VH |
| Cm (g/l) | 51.74 | 45.82 | 44.47 | 54.04 | 107.84 | 90.63 |
| Kr (%) | 45.77 | 78.79 | 80.09 | 50.42 | 85.09 | 77.48 |
| Kr max (%) | 85.13 | 93.52 | 98.32 | 81.81 | 95.45 | 98.48 |

(D: Dry H: Humid, VH: Very Humid, Cm: mean concentration; Kr: runoff coefficient; Kr max: maximum runoff coefficient).

***The runoff coefficient***

In general, runoff coefficients are higher on wet ground and very humid (61 to 87%) than on dry ground (14 to 50%).

The runoff coefficient is higher for wet and very wet soils and can grow up to 87.5%. In dry soils, law values were recorded from 14 to 50%, this is mainly due to the importance of soaking rain that can reach up to 35 mm it has a direct relationship with the structure soil.

On the other hand, once the intensity of the rain is increasing the value of the runoff coefficient increases by 10 to 100% by passing a rain intensity of 30 to 50 $mm/h^{-1}$ and 10 to 60% passing an intensity of 50 to 80 $mm/h^{-1}$, and increased by 300% from 30 to 80 $mm/h^{-1}$.

The effect of the slope generally promotes increased runoff coefficient, the passage of a slope of 12.5% to 25% increases of "Kr". This is mainly due to the reduction of the braking effect by friction of the flow of water on a steep slope with respect to a lower slope.

Runoff coefficient varies with the prior moisture of soil, the slope and the intensity of the rain. The variation of "Kr" according to the different parameters is shown in the histogram of Figure 5.

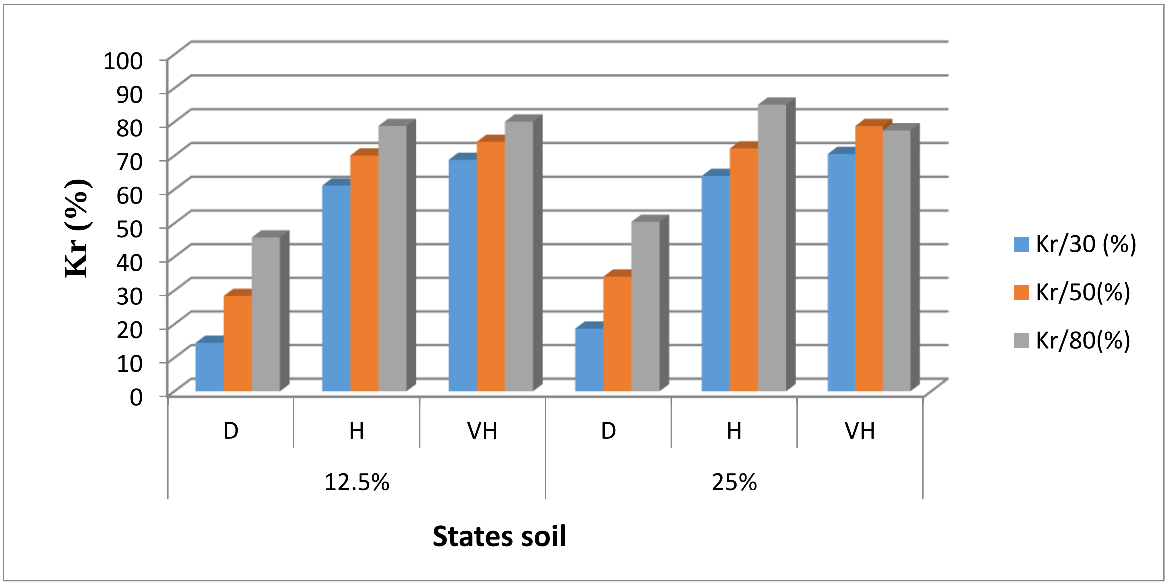


**Figure 5.** Variation of the coefficient of runoff for different cases of studied soils

**Search for the relationship between the measured parameters**

The relationships found with their correlation coefficients "$R^2$", calculated for each linear and logarithmic models for the relation: C = f (Kr) are grouped together in Tables 6 and 7.

**Table 6.** Relations between "C" and "Kr" by the linear model

| Intensity (mm/h) | Slope (%) | States soil | Expression | R2 |
|---|---|---|---|---|
| 30 | 12.5 | D | C= 44.39-0.08.Kr | 0.63 |
| | | H | C= 43.73-0.16.Kr | 0.02 |
| | | V.H | C= 46.89-0.21.Kr | 0.13 |
| | 25.0 | D | C= 46.91-0.08.Kr | 0.67 |
| | | H | C= 60.75-0.40.Kr | 0.76 |
| | | V.H | C= 61.53-0.37.Kr | 0.28 |
| 50 | 12.5 | D | C= 49.23-0.17.Kr | 0.94 |
| | | H | C= 3.75+0.44 .Kr | 0.88 |
| | | V.H | C= 2.88+0.40.Kr | 0.40 |
| | 25.0 | D | C= 66.5-0.36.Kr | 0.70 |
| | | H | C= -31.18+0.86.Kr | 0.81 |
| | | V.H | C= 18.2+0.67.Kr | 0.73 |
| 80 | 12.5 | D | C= 90.54-0.60.Kr | 0.45 |
| | | H | C= 9.01+0.48.Kr | 0.85 |
| | | V.H | C= 44.21+0.01.Kr | 0.001 |
| | 25.0 | D | C= 129.8-1.09.Kr | 0.74 |
| | | H | C= 129.4-0.25.Kr | 0.39 |
| | | V.H | C= 53.47+0.43.Kr | 0.40 |

**Table 7.** Relations between "C" and "Kr" by the logarithmic model

| Intensity (mm/h) | Slope (%) | States soil | Expression | R2 |
|---|---|---|---|---|
| 30 | 12.5 | D | LogC =4.06-0.10. LogKr | 0.56 |
| | | H | LogC = 5.32-0.43 LogKr | 0.02 |
| | | V.H | LogC = 6.55-0.71 LogKr | 0.14 |
| | 25.0 | D | LogC = 1.36-0.03 LogKr | 0.36 |
| | | H | LogC = 2.85-1.11 LogKr | 0.80 |
| | | V.H | LogC = 3.34-1.43 LogKr | 0.43 |
| 50 | 12.5 | D | LogC = 4.51-0.21 LogKr | 0.87 |
| | | H | LogC= -0.01+0.83 LogKr | 0.70 |
| | | V.H | LogC= -1.67+1.15 LogKr | 0.43 |
| | 25.0 | D | LogC = 4.80-0.25 LogKr | 0.73 |
| | | H | LogC= -5.46+2.07 LogKr | 0.85 |
| | | V.H | LogC = -3.0+1.5 LogKr | 0.74 |
| 80 | 12.5 | D | LogC = 7.06-0.75 LogKr | 0.47 |
| | | H | LogC = 0.28+0.81 LogKr | 0.87 |
| | | V.H | LogC = 3.71+0.01 LogKr | 0.02 |
| | 25.0 | D | LogC = 9.60-1.33 LogKr | 0.76 |
| | | H | LogC = 5.39-0.16 LogKr | 0.33 |
| | | V.H | LogC = 2.76+0.39 LogKr | 0.40 |

## Conclusion

The results from the application of the rain simulation technique has led us to draw the following conclusions:

The runoff volume increases as the moisture condition of the soil, slope and rainfall intensity raise. Once the soil is gradually saturated with water, it gives way to a runoff, which is favored by the compaction of the soil surface.

Sediment transport is important for dry soils and begins to decline as the soil becomes wetter. The runoff coefficient is proportional to the three parameters taken into consideration, it increases with the intensity of rain (30-80 mm/h), with the slope and the state of soil moisture.

Expressions explaining the relationship between concentration and runoff coefficient for different soil moisture conditions are given below:

- For dry soils:

C = 65.16- 0.24.Kr N = 60; R2 = 0.68

Log 4.36-0.42.Log.Kr C = N = 60; R2 = 0.62

- For wet soils:

C = 45.07 + 0.52.Kr N = 60; R2 = 0.73

Log C = 3.54 + 1.12.Log.Kr N = 60; R2 = 0.71

- For very wet soils:

C = 35.42 + 0.62.Kr N = 60; R2 = 0.56

Log C = 2.86 + 1.08. Log.Kr N = 60; R2 = 0.50

(N: sample size)

The influence of soil moisture condition appears clearly in the two cases considered.

Dry soil promotes better sediment transport, due to the disintegrated state of soil particles on one hand and reducing runoff which is directly related to increased infiltration. By cons for moist to very wet the opposite phenomenon occurs, the flattening of the surface results in a run-off but with a reduced sediment transport.

Good control of this technic and the intensification of simulation tests in different areas and for several campaigns, lets in as soon as possible to have significant results on the rate of erosion upstream and find appropriate solutions in the fight against water erosion before it affects its negative consequences on dams on the one hand and on the other floor.

Understanding of runoff and erosion allows therefore to guide the selection of appropriate accommodations that will surely have a positive ecological, economic and social impact.

Ultimately, we can save two significant non-recurring items namely water and soil, realizing four main goals:

- The conservation of our existing water resources by limiting the silting of dams.

- Protection of vulnerable soil by applying modern methods can be particularly useful in the Mediterranean context where some of the effects of climate change (desertification and drought) will increase as interesting forest areas and intensifying the problem related to the protection soil.

- The fight against land degradation by applying all possible procedures such as reforestation and correction works at the watershed level.

- Awareness of the mountain population to a reasonable use of land and water resources.

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