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QUANTITATIVE EVALUATION OF ERODED SEDIMENTS IN THE UPPER IBRAHIM RIVER WATERSHED, LEBANON

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Abstract

Soil erosion is one of the major problems facing the mountainous agricultural lands in Lebanon. Sediments carried in the river water are a criterion of pollution. In order to determine the quantity and acting factors of soil erosion, a study was conducted in the Upper watershed of Ibrahim river. Thus, seven localitieswere investigated on the two major streams feeding the river, located between 808 m and 1488 m in altitude. These localities are connected to sub-basins representing 88.9% of the river watershed (312.7 km^2). Water samples were collected during the spring season in April, May and June 2013. Suspended sediments were determined by decantation. Simultaneously bed load samples were taken in order to determine their texture as well as their mineral composition. Water flow and sediments load were the highest in April, in all sub-basins. Sediments load reached 713.72 mg L^{-1} and 298.60 mg L^{-1} for the localities 2 and 3 in April and decreased to 61.77 mg L^{-1} and 25.94 mg L^{-1} in May. The monthly eroded soil reached 704 tons during April in location 2 and 662 tons in location 6. Within each sub-basin the land cover, slope length and gradient influenced water sediments load. Where orchards are predominant, such as in the upper watershed, high soil erosion was found. The sub-basin predominated by grassland (52.64% of area) and stable bare rocks (45.11% of area) generated lower sediments load.

Key words: Ibrahim river, snow melting, erosion, land cover, sediments.

Introduction

Lebanon climate is generally Mediterranean with hot dry summers and cold rainy winters. A small and mountainous country, Lebanon presents a complex geomorphology and several agro-ecological zones caused by different agro-climatic conditions and complex orography. The Mount-Lebanon zone extends from the North to the South hills with a total length of 160 km. Mount-Lebanon zone includes a large number of catchments which vary in size. Most of these coastal rivers are fed by rain, snowmelt and karstic springs. The hydrological regime of these rivers is characterized by high flows in winter caused by intense precipitation as well as a spreading of these flows during the spring supported by snowmelt. Lebanon enjoys abundant ground and surface water, but the supply of potable water has been reduced by pollution caused by population growth, industrial development and expansion of irrigated agricultural land (El-Fadel et al., 2000). The unregulated exploitation and overpumping of private wells have also impaired aquifer quality (Jurdi, 1992; El-Moujabber et al., 2006; Darwish et al., 2011).

In agricultural lands, fertilizers increase the soil contamination with nitrogen and phosphorus. These may appear in the stream after a heavy rain due to soil erosion and runoff water. Soil erosion is one of the major causes of land degradation in Lebanon (BouKheir, 2006). Soil erosion is critical in Lebanon due to the steep topography, the lack of wide coastal plain and to the absence of the protective land cover and inappropriate land, forestry and watershed management. This study focuses on Ibrahim river catchment with a basin area of 326 km^2 and a slope gradient of 55 to 60 m km^{-1}.The river length is 44 km and presents an annual discharge of 328 Mm^3. This study was conducted in the upper watershed of the river during snow melting with the objectives of characterizing the sediments carried in the water during three spring months.

Materials and method

Ibrahim river watershed

The Ibrahim river basin is influenced by Mediterranean climatic conditions especially temperature and precipitation. The precipitation ranges between 900 mm and 1400 mm with an average of 1108 m. The land cover in the watershed plays an important role in controlling the erosion processes. It is one of several important factors affecting the infiltration rate and runoff water. Dominated by bare soil (123.9 km^2), then by woodland (120.3 km^2), agricultural land occupies 8% of the watershed area.

Sampling and analysis

The study was done in seven sites in the upper stream (Table 1). Samples were collected during three monthly visits: 17 April, 11 May and 16 June 2012. Water flow in sites 1, 2 and 3 was not permanent.

Table 1. Coordinates, the altitude and the main textural class of the soils found in the seven sampling locations.

	Longitude	Latitude	Altitude (m)	Textural class
1	34° 7’34.72"	35°53’45.63"	1488	Clay Loam
2	34° 7’33.78"	35°53’50.68"	1457	Clay Loam
3	34° 7’32.26"	35°53’54.05"	1438	Clay Loam
4	34° 7’20.71"	35°54’29.01"	1324	Loam
5	34° 6’32.12"	35°54’28.41"	1250	Clay Loam
6	34° 6’28.42"	35°53’23.37"	1119	Clay Loam
7	34° 5’19.28"	35°51’49.93"	808	Clay loam

Water samples collected in a 5000 mL plastic gallon, were subjected to decantation for 2 weeks. Then the clear water was pumped with a manual pump. The decantation was repeated till a volume of 20 mL was achieved, then the samples were dried in an oven at 105°C. The water flow during each monthly visit was obtained empirically, by determining the speed of a moving object and the cross-section of the site. The water flow and the suspended sediments allowed to calculate the monthly amounts of sediments. Bed load samples were dried in the oven at 45°C. Then a sub-fraction (200 g) was passed on a plastic sieve (63 µm). The fractions larger than 63 µm were passed through three sieves 2000 µm, 250 µm and 180 µm. Then the 5 fractions were weighed.

Soil data

Soil data were retrieved from the Soil and Terrain database (SOTER), based on the new soil map of Lebanon at 1:50,000 scale (Darwish et al., 2006). SOTER is a relational database system that provides complete information on the soil i.e., location, landform, lithology, slope gradient, drainage conditions, erosion, surface stoniness, texture, rootable depth, diagnostic horizons and other physical and chemical properties (Darwish et al., 2000).

Results and discussion

Land cover and soil properties

The area of the sub-basins varied between 1.4 hectare for sub-basin 3 and 18388.1 hectares for sub-basin 7 (Table 2). Land use of the sub-basin feeding each location was established. Agricultural lands were predominant in sub-basins 1, 2, 3 and 6.

Of the soil properties affecting the erosion, soil texture and organic matter content play an important role. The textural classes of the soils surrounding the sampling sites were mainly clay loam (Table 1). The sand fraction varies between 29.94% and 39.37%, the clay content between 23.28% and 38.26%, and the silt from 21.81% to 36.49%. Soil organic matter has an effect on soil aggregation which in turn influences soil water infiltration, moisture content and drainage. Lebanese soils are poor in organic matter (Darwish et al, 2009) with a limited ability to aggregate. Soils with high clay and organic matter contents increase the potential for aggregate formation that lead more to soil stability and prevent erosion (Rice, 2002). Thus the studied sub-basins are more susceptible to erosion due to low soil organic matter.

Table 2. Land cover in the sub-basins feeding the 7 studied locations in the watershed of Ibrahim river.

	Land cover (% of area)						
Sub-basin	Buildings	Agricultural land	Woodland	Grassland	Bare soil and rocks	Lake	Area (ha)
1	0.00	71.25	0.00	21.55	7.06	0.14	82.9
2	0.00	54.22	7.94	13.66	21.48	2.70	225.2
3	0.00	60.95	0.30	38.752	0.00	0.00	1.4
4	0.00	0.63	1.62	52.64	45.11	0.00	8618.6
5	0.00	0.00	99.19	0.00	0.81	0.00	21.2
6	< 1%	60.73	12.78	20.92	3.75	1.34	471.6
7	< 1%	5.84	8.79	49.25	35.46	0.11	18388.1

Slope

Soil particles can be detached and transported from the soil surface, especially when located on steep land. Increased run-off occurs on heavier soils when soil structure is poor and the soil has lost its ability to soak up melting snow. This run-off may be sufficient to scour and detach fine soil particles leading to discoloured run-off (also known as soil wash). However, it does not always cause rill formation. Any improper cultural practices, or compaction caused by these operations will increase surface run-off and erosion risks. At the higher altitudes of each sub-basin, ranged between 1715 m and 2573 m (Table 3), the energy of rain splashing is absent in the period from April to June, due to the snow cover. Soil freezing causes the deterioration of aggregates leading to the transport of fine soil (clay particles) by runoff water (Ollesch et al., 2005). This could explain why even soils with high clay contents are subject to erosion. Low levels of clay and the combination of several factors could explain the high level of sediments in the sub basin 2. A similar range of clay was recorded for the other sites.

The intensity of erosion caused by snow melt is determined by the rate of melting, the amount of water equivalent, soil permeability, disintegration of soil aggregates caused by frost, moisture in the soil and vegetation. Melting rates are usually much smaller than the intensity of rain but frozen soil in the surface layer may reduce the infiltration rate. Repeated freezing and thawing of soil plays a considerable role in the degradation of soil erosion by water. During the process of snow melt combination of intense rainfall, frozen soil and saturated soil surface leads to erosion and development of serrated ravines. Not taking into consideration the sub-basin 3 because of its small area (1.4 ha) and sub-basin 5 fed by groundwater (*Roueiss* spring), the slope of the sub-basin 2 was the highest (20.7 degrees) with land use occupied by agricultural lands (71.25%). These factors explain the high load of sediments in location 2. The effect of the slope meets the conclusion obtained in a study on terraced orchards in two Greek islands, where soil erosion increased significantly when the slope gradient reached 25% (Koulouri and Giourgo, 2007).

Table 3. Higher and lower points of each sub-basin feeding the 7 sampling locations in the upper watershed of Ibrahim river.

Sub-basin	Length (km)	Lower point H min (m)	Higher point H max (m)	Slope (%)
1	2.64	1488	2063	15.7
2	2.74	1457	2090	20.7
3	0.34	1438	1715	30.4
4	16.54	1324	2573	15.2
5	0.70	1250	1868	35.5
6	4.80	1119	2038	17.5
7	19.48	808	2573	15.2

Sediments in the Upper Ibrahim river watershed

Sediments are the largest water pollutant that affects water quality physically, chemically and biologically. In this study the sub-basin 3 showed a high level of erosion per unit area (11.61 tons ha^{-1}) followed by sub-basins 2 and 6 (Table 4). Because of its very small area, the sub-basin 3 will be excluded from the discussion. The level of sediments in April 2013 was higher than those during May and June 2012despite the higher temperatures intensifying snow melt due probably to soil warming and improved recharge. Locations 1, 2, 3 and 6 were alimented by runoff water due to the melting of the snow at this period. Location 4 was alimented by a huge watershed, whereas location 5 was directly alimented by *Roueiss* spring. Finally location 7 was at the convergence of the two springs *Afqa* and *Roueiss* (Table 4).

Table 4. Monthly flow, concentration of suspended sediments and sediments lost per unit area of each sampling location during April, May and June 2012.

	Location	Flow (m^3)	Sediments ($mg\ L^{-1}$)	Sediments (tons $month^{-1}$)	Sediments (tons ha^{-1})
April	1	620524.8	88.87	55.1	0.67
	2	987033.6	713.72	704.5	3.13
	3	54432.0	298.60	16.3	11.61
	4	6270566.4	9.64	60.5	0.01
	5	64180000.0	2.66	170.8	8.06
	6	4149273.6	159.59	662.2	1.40

	7	Not accessible			
May	1	74995.2	21.81	1.6	0.02
	2	404974.1	61.77	25.0	0.11
	3	13499.1	25.94	0.4	0.25
	4	742452.5	21.74	16.1	0.00
	5	45356000.0	2.27	103.0	4.86
	6	1967017.0	11.65	22.9	0.05
	7	91854000.0	8.8	808.3	0.04
June	1	Dry			
	2				
	3				
	4	20736.0	0.00	0.1	0.00
	5	19168000.0	0.89	18.9	0.89
	6	298598.4	0.00	0.6	0.00
	7	39779000.0	0.01	194.0	0.01

The main variables affecting water erosion are precipitation and surface runoff. The impact of raindrops striking the soil surface can detach the soil particles, break down soil aggregates and disperse the aggregate material causing splash erosion. Experiments with artificial rainfall showed that sediment concentrations tended to increase not only with the slope gradient but also with slope length, particularly when side-slope gradients exceeded 10%. The effect may be the result of a change from erosion dominated by raindrop detachment and raindrop-induced flow transport to erosion dominated by raindrop and flow transport (Kinnell, 2000).

Bed load sediments

Bed load sediments were separated into 4 classes according to their size (Table 5). For the locations 2 and 3 the percentages of the fraction below 63 µm were higher than the other locations. Usually the fraction smaller than 63 µm is transported in water as total suspended solid but some of it will deposit on the bottom of the steam as the velocity of water decreases. The quality of the particles found in the bed load reflects to a large extent the type of soils surrounding the watershed. The range of sand in the region surrounding the sites 1, 2, 3, 4, and 5 was between 16 and 47% whereas for the locations 6 and 7 it increased to 64 and 82%. The high occurrence of sand in surrounding soils was reflected in the values of sand in the bed load sediments 80.9% in the location 6 and 78.25% in the location 7. Location 5 was dominated by gravel (65% of sediments) reflecting the origin of this water as ground water. The bed load textural classes showed that in locations 1 and 6 no change was noticed with time, indicating the homogeneity of eroded soil in these sub-basins. The absence of homogeneity in the other locations could be linked to changes in the water velocity during snow melting leading to erosion deposition and migration of soil particles along the river.

The bed load samples were subjected to several tests in order to determine the concentration of available nitrate, phosphorus, potassium and the percentage of organic matter. The available nitrate ranges from 4.9 to 18.8 mg kg^{-1}, from 1.4 to 8.6 mg kg^{-1} for Olsen phosphorus, from 40 to 250 mg kg^{-1} for exchangeable potassium and from 3 to 15 g kg^{-1}for organic matter (Table 5). Nitrates are easily leached from the soil with high rainfall. All the samples were in a range between low to medium except for the location 1 that showed a high level of nitrate compared to the other locations. Olsen test estimates the plant-available phosphorus. All samples showed a low level of available phosphorus illustrating the low mobility of phosphorus in soil. Available potassium ranged between low to medium levels in the sediments samples. The K concentrations found in the locations 1, 2, 3 and 6 suggest a significant contribution from heavily fertilized agricultural land.

Table 5. Concentrations of minerals in the bed load sediments sampled in April, May and June 2012.

Location	Date	Concentration (mg kg^{-1})			Organic matter
		Nitrate	Olsen-P	K	(g kg^{-1})
1	April	18.8	8.6	250	15
	May	13.4	7.6	170	12
2	April	6.7	2.7	90	5
	May	5.4	5.2	150	5
3	April	5.8	1.4	150	5
	May	5.8	5.1	140	5
4	May	13.8	2.8	20	12
6	April	7.1	3.7	80	7
	May	6.7	3.6	70	5
	June	4.9	5.1	120	5
7	May	4.9	3.9	50	3
	June	11.2	3.9	40	7

Conclusion

This study was conducted to evaluate the quantity of eroded soil in the upper watershed of Ibrahim river during snow melting. Water load sediments tended to be favoured by the snow melting that increased water flow. The total quantity of lost soil was the highest in location 7, which was fed by all studied sub-basins, during May 2012 (808 tons), followed by location 2 in April 2012 (704 tons) then by location 6 during the same month (662 tons). An important quantity of sediments was delivered in the river with some 1669 tons from the first 6 locations in April. This quantity of sediments will significantly contribute to the degradation of agricultural land.

Data revealed that the high level of suspended sediments in water was influenced by the land cover especially agricultural land dominated by orchards. Their occurrence on steep land, in the absence of cover crop and under poor agricultural practices, lead to high levels of eroded soils. This value reached 11.61 tons ha^{-1} in location 3. In sub-basin 4 low levels of sediments were generated because of the grassland (52.64% of sub-basin area) acting as ground cover, on one side, and the bare rocky ground (45.11% of the area) on the other. Sub-basins dominated by orchard delivered a huge quantity of sediments in the river. Action must be taken in order to preserve this productive soil by improving the knowledge of the farmer for the application of better agricultural practices as cover crops, mulching and reduce the frequency of ploughing. Further studies must be done during the autumn season with the first rains in order to obtain the full water load sediments.

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