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RECENT EROSION MEASUREMENTS IN MOROCCO

Abstract: The paper describes selected investigations concerning the progress of erosion in various regions of Morocco which were carried out from 1990 onwards by a group of geomorphologists sponsored by UNESCO. It was found that the intensity of erosion, especially in recent years, is linked to fast socio-economic development and incorrect management of the exploitation of natural resources. Extensive grazing, deforestation and expansion of agriculture on frequently unsuitable soils are of great importance here. These activities caused a decrease in the infiltration of precipitation water into the subsoil, thus soils became less humid and ground water resources decrease. Simultaneously increased runoff causes mud accumulation and pollution in man-made water reservoirs, which play an important role in water supply during dry periods.

The first studies in this project were made in the forest of Mamora and in the region of Bou Khouali – Tanecherfi (eastern Morocco) in the years 1990-1995. They assessed the process of soil erosion and its intensity. On the basis of the results obtained it was found that type of soil and kind of land use were the main factors influencing the process of soil degradation; these factors being characteristic for individual regions of different climate.

The second set of studies described were carried out in the regions of Tatoft and Benslimane in the years 1996-1999 as a part of the MEDCHANGE (INCO-MED) project in cooperation with Aveiro University. These studies concerned surface flow and erosion rate determined with the use of precipitation simulators. It was recognized that the smallest surface flow occurs in natural oak forests, however this is twice as high when there is grazing in the forest, and four times higher in those areas where trees were cut down and the resulting clearfell areas are used as pasture. Moreover, the studies have shown that the total amount of mineral and organic material which has been eroded depends to a large degree on the intensity of the surface flow, though this relation is not linear. Even scarce plant cover, e.g. matorral (shrubland), n an area being considered is an important factor causing compacting of the soil and retention of the mineral sediment.

The third group of investigations were experiments performed in the region of Sehoul, close to Rabat City in the years 2000-2003 in the project CLIMED (INCO-MED ICA3-2000-30005) in cooperation with Aveiro University and concerning hydrologic reaction and bottom transport.

Erosion connected with rainfall was recognized by means of the hydrologic model LISEM. It was found that the surface flow depends on a low infiltration capacity of the dusty-clayey soils occurring in the drainage area investigated, low soil humidity retention due to the limited thickness of the soil layer or the presence of an impermeable bed and scarce vegetation in wastelands and pastures.

Key words: erosion studies, erosion reasons, material transport, soil erosion, land use, Morocco.

In the Mediterranean regions of Morocco, characterised by irregular rainfall and intense storms, the sensitivity of the environment to anthropopressure is high (Chaker 1995, Coelho et al. 2000, 2002, Laouina et al. 2004, Nafaa et al. 1997). The process of land degradation is increasingly linked to socio-economic changes and resource management. Grazing and forest exploitation are still important, coupled with an extension of the cultivated areas. Overgrazing, over-exploitation of wood and the location of agriculture on unfavourable land lead to extreme soil erosion and dangerous silting of artificial reservoirs. The concentration of the population and flocks of grazing animals on poorly consolidated slopes explains the retreat of the vegetation cover, the rapid soil degradation and the spreading of rills and gullies.

These negative impacts on the environment constitute a threat to the sustainability of the current process of development. The rapid rate of change requires an urgent response to prevent the extension and increase of such degradation.

Land degradation threatens the recharge of groundwater systems. This land degradation is linked to the agricultural transformation, currently taking place, causing an increased pressure on the cultivated area, grazing grounds and forests, and deficient management of their natural resources (Chaker 1995, Conacher, Sala 1998, Laouina et al. 2000, Nafaa et al. 1997). These transformations include the growth and ageing of the rural population, the increasing complexity of landownership (number of regulations, predominance of small land holdings, scattering of fields due to inheritance, the increasing number of those entitled to use common land), and the urbanisation of high-quality agricultural land surrounding urban areas (Laouina et al. 2003). In addition, the traditional smallholder agriculture is marginalised in favour of modern, large-scale agriculture, whereas the latter is mostly responsible for the inefficient use of water, the pollution of soils and groundwater and a growing salinity of irrigated land (Laouina et al. 2000).

Land degradation is manifested by a decrease of vegetation cover resulting from deforestation, loss of topsoil by water and wind erosion, crusting, overgrazing, compaction by cattle and hardpan formation in soils. The deforestation and the extension of the cultivated area date from the early 20th century. The limits of most of the forest areas were fixed in the years 1920-1930, but inside the forests and in the remnant pastures, internal degradation by overgrazing and wood gathering still continues. In the cultivated area the reduction of the surface and period in fallow and the mechanisation and ploughing in the direction of the slope cause ongoing land degradation due to the thinning of soils, crust formation and compaction.

All these phenomena decrease the infiltration of rainfall, keeping water back from the soils that otherwise may be stored in the soil horizons and percolate to the shallow groundwater. At the same time, the increasing discharges of runoff over the land surface cause the silting and pollution of artificial reservoirs, which play an important role in the regulation of water provision in the dry season (Laouina et al. 2000). These problems are not limited to the region southeast of Rabat, but also apply in other mountainous and semi-arid areas in Morocco as well, like the Pre-Rif Mountains.

From 1990, the team of geomorphologists of the "UNESCO Department of Environmental Management and Sustainable Development" conducted research on erosion in many regions of Morocco. Much of this work was carried out in cooperation with other research institutions in the framework of joint projects, some of them funded by the EU.

1. Measurements in the Mamora Forest and in Eastern Morocco (1990-1995)

With the support of the Forestry Administration, a team of geomorphologists carried out field research for a period of 5 years, from 1990 to 1995, to assess the impact of changes induced by humans and to estimate the response of the environment to these important changes.

Two main field research areas have been studied, and in each, many sites were observed. We investigated the main problems of land degradation in the two areas: a survey of vegetation retreat; an evaluation of the sheet wash effect; mapping of the extension of gullies; an estimation of soil removal by wind and an assessment of the depletion of the water table (Laouina et al. 1992, Chaker 1995). Experimental plots of 100 m^2 were established at each site with equivalent slope angles and the same soils, but different soil covers and uses. The plots were used to measure total rainfall and rain intensity, runoff, suspended load and soil loss. The suspended load was measured in samples of runoff accumulated from the plots after every rain event. Samples were dried before measuring the weight of the material transported.

The comparison between similar plots under different climatic and pedologic conditions has shown the following:

– In a semi-arid environment, the Bou Khouali-Tanecherfi region (Eastern Morocco), the natural open vegetation and crop covers have a quite similar behaviour, with a weak rate of protection. It is only under a relatively dense matorral (more than 30% of the soil covered) that high runoff[1] was rare;
– On a sandy soil, on the southern border of the Mamora Forest, the occurrence of intense runoff events is significant in nearly all situations and only the natural cork-oak forest provides good protection. Wheat cropping has a quite significant effect under normal rainfall conditions but it is inefficient under continuous and intense rains.

[1] An erosive rain is defined as a rain event which produces more than 0.1 mm of runoff (a streaming of 10 litres from a plot of 100 m^2); a high runoff is an event of superficial streaming which exceeds 1 mm (100 litres from a plot of 100 m^2, or 10 m^3 from each hectare).

In sub-humid conditions, year-round cultivation constitutes a good protection. Indeed, on sandy and dry soils the early rains, unless very heavy, infiltrate better into ploughed fields and the rapidly growing high-density cereal crops prevent runoff during winter and springtime. In hilly areas, even moderate slopes present a very poor choice for special types of cultivation with a high proportion of uncovered soil. Maize, for example, can only be grown in really flat areas.

2. Rainfall simulations in Tatoft and Benslimane (1996-1999)

Under the scope of the MEDCHANGE project (INCO-MED), in cooperation with Aveiro University, rates of overland flow and erosion rates were determined with the help of a rainfall simulator. It consisted of a sprinkling device placed at 2 metres above ground and providing a reasonably homogeneous rainfall intensity of 50.5 mm per hour over a 1 m^2 area. A small 0.24 m^2 circular-shaped plot was inserted carefully in the soil. Inside the plot, a TDR Theta probe was inserted to a depth of 6 cm. Measurements of overland flow and soil moisture content were taken at one minute intervals. Overland flow samples were collected for sediment determination, three within the first 15 minutes after the beginning of the initiation of the overland flow, the fourth in the middle of the experiment, and a fifth at the end of the experiment. Rainfall simulation experiments were performed for one hour.

A soil sample was collected after the rainfall simulation and 20 measurements of soil resistance to penetration and to torsion were performed in selected places around the plot at each experimental site. Soil resistance was assessed through the use of a pocket penetrometer and a torvane. A 2 mm sieve was used to divide the soil samples. Then a Coulter LS Particle Size Analyser performed a soil texture measurement for the fraction under 2 mm. Organic matter content was determined by Loss on Ignition at 550^{o}C during 120 minutes.

All the areas studied lay within the region where *Quercus suber L.* forms the natural climax vegetation (i.e. with annual rainfall amounts between 500 and 900 mm). All the areas have a marked summer dry period.

Overland flow generation

The *Quercus suber* stands form a more conservative land use, with smaller rates of overland flow, inferior to 10% of rainfall on average. An increase of grazing pressure within the *Quercus suber* stands leads to significantly higher rates of overland flow. The complete removal of the trees enhances overland flow generation to the double of overgrazing within forest stands and changes the soil moisture structure of the ploughed fields (traditionally running down the slopes, as a result of an extreme level of property fragmentation). Fallow overland flow reaches a maximum of 53.5% of rainfall. During fallow years, much of the arable land fallow is used for sheep, goat and cattle grazing. Therefore the soil is extremely compacted and produces high overland flow rates. The same pattern happens for the matorral land use types. Although not ploughed, the extreme grazing pressure enhances overland flow in these areas.

The introduction of new forest stands (pine or eucalyptus) increases the amount of overland flow, in some cases due to soil water repellence or to the small amount of understorey vegetation and thin litter layer.

Sediment and organic matter erosion yields

Although overland flow rates have a strong influence on erosion yields, the relationship is not linear. In fact, the *Quercus suber* stands present the lowest erosion rates (less than 1 $g{\cdot}m^{-2}{\cdot}h^{-1}$ on average). Despite the high overland flow rates, the relatively undisturbed matorral areas present low soil erosion rates (typically inferior to 10 $g{\cdot}m^{-2}{\cdot}h^{-1}$, which means that the vegetation has an important impact on the soil's internal coherence and on sediment trapping). For these relatively undisturbed soils, the eroded organic matter typically represents more than 10% of the total eroded sediments; in some cases this value represents 30%. This means that the soil has a significant top organic matter layer that is mobilized during particularly intense rainfall events.

3. Research on hydrological response and bed load transport in the Rabat region (2000-2003)

Experimental studies were carried out in the Sehoul region as part of the CLIMED project (INCO-MED ICA3-2000-30005), in cooperation with Aveiro University and the ALTERRA Institute . A small catchment basin (70 ha) was installed in the Matlaq area, near Rabat. This catchment has low infiltration capacity in the frequently ploughed humic cambisols which are mainly used for agriculture and grazing.

A twin-pronged approach was chosen to handle the different temporal and spatial scales of the infiltration of rainfall in the soils and the behaviour of the groundwater systems. The influence of land degradation on infiltration was analysed by studying the hydrological behaviour of the catchment at the scale of individual rainfall events. Abstractions from rainfall were modelled using the LISEM hydrological catchment model.

The experimental design, including rainfall simulation, had the objective of assessing overland flow and sediment yield at a slope scale. A weir with water level recorders was installed. In addition, the weir was placed in a manner which created a pool to trap bed load sediments.

Surface runoff was modelled for the Matlaq catchment using the event-based Limburg Soil Erosion Model. This model was developed to simulate surface runoff for individual rain events in small agricultural catchments. GIS-based, LISEM can handle spatially distributed parameters and initial conditions, and produce spatially distributed outputs of surface runoff variables at any time during the simulation. Lumped outputs like the total rainfall, total volume of surface runoff and discharge at the outlet are also provided.

LISEM works with maps of physical parameters of the soil, soil surface parameters and crop parameters. These maps were constructed by attributing parameter values to fields based on their land use and soil type.

Initial conditions for LISEM comprise the soil surface roughness and the initial soil moisture content. The soil surface roughness for the calibration event was taken from field measurements.

The surface runoff production is the result of several factors:

– The low infiltration capacity of the silty clay soils, aggravated by sealing and compaction by cattle. This influence is reflected in small values of the saturated hydraulic conductivity (<1 mmh^{-1});
– The limited soil moisture storage capacity due to the limited soil depth (40 cm for soils on the eroded south-east oriented hill slope) or due to an impeding horizon (calcic horizon or Bt-horizon in the fersiallitic soils);
– The weak vegetation cover of the fallow and grazing fields, reflected in small values of the leaf area index.

The results show that the catchment has an event runoff generation response, with large and fast peaks in response to intense rainfall events (fast Hortonian response to intense rainfall and no water during long dry periods).

A study was made of the sediment and overland flow processes at slope scale and their influence on the runoff patterns and bed load transport. This was intended to help identify the impact of different land management systems upon hydrological and erosion processes.

The results of the surface modelling with LISEM show that surface runoff – but not necessarily soil erosion – is mainly produced in ancient grazing fields and fallow fields. Fallow fields are less susceptible to runoff production when left with significant vegetation cover in winter and spring and crop remnants in autumn (which means a reduced grazing pressure). In a comparison of runoff intensity on fields with different land use and management, runoff production is highest on ancient grazing fields which have experienced soil degradation in the past due to over-use in cultivation. Recently tilled fields are in second place due to the destruction of the soil structure, crusting and rill formation. However, despite the smaller volumes of surface runoff produced, recently tilled fields record much more erosion than ancient grazing grounds, especially as a result of autumn rain storms (Laouina et al. 2003). This is explained by the concentration of surface runoff in the furrows of the tilled fields and the formation of rills, especially when tillage is in the direction of the slope. The surface runoff from the grazing fields is less concentrated and can even benefit crop growth and groundwater recharge by re-infiltration in down slope areas; in some cases, this runoff with low sediment content, can benefit water storage in artificially dammed reservoirs, which represent the main resource to extend irrigation and improve water availability in cities. The surface runoff simulations confirm that less runoff is produced on cultivated fields compared to grazing fields, even when tillage is in the direction of the steepest slope. However, the simulations do not indicate the type of surface runoff occurring, neither the associated soil erosion.

Changing the tillage direction to that of the slope contour on cultivated fields reduces the total and peak discharge at the catchment outlet, but only when the surface runoff is not allowed to concentrate in tillage furrows and the hydraulic roughness and surface depression storage are already small. This condition occurs when the soil surface is levelled after tillage.

Less runoff is produced on fields tilled and planted with cereals early in the autumn season and fields which have recently lain fallow, not tilled in autumn and left with crop remnants. In view of the current transformation of collective grazing fields into cultivated land, problems with loss of rainfall in surface runoff and soil erosion could be mitigated by early tillage of cultivated fields along the slope contour, followed by levelling, locating cultivated fields down slope of grazing fields to enable the capturing of diffuse surface runoff coming from the grazing fields, and leaving fallow fields untilled and covered with crop remnants.

References

Chaker M., 1995, *La dégradation actuelle du couvert végétal dans le massif de Boukhouali, processus et impact sur l'équilibre du milieu*, Publ. de l'Association des Géographes Africains, Rabat, 87-102.

Coelho C.O.A., Ferreira A.J.D., Regaya K., Laouina A., Hamza A., Boulet A.K., Keizer J.J., 2002, *The role of land-use changes in reservoir siltation in the Magrheb region and its implications for rural planning*, Hydromed. Séminaire International des petits barrages dans le monde méditerranéen, Tunis, 28-30 May 2001.

Coelho C.O.A., Laouina A., Ferreira, A., Naciri R., Chaker M., Nafaa R., Carvalho T.M.M., Boulet A.K., Pereira J.B.P., 2000, *Forest and grazing impacts on hydrological and erosional processes in Southern Portugal and Northern and Central Morocco. Man and soil at the third millennium*, Geoforma Ediciones.

Conacher A., Sala M. (eds.), 1998, *Land degradation in Mediterranean environments of the world*, Wiley, 491.

Laouina A., Chaker M., Nafaa R., 2003, *Suivi et mesure de l'érosion hydrique des terres au Maroc, 15 ans de recherche et d'expérimentation*, Rev. Géogr. Maroc, 21, 79-98.

Laouina A., Coelho C., Ritsema C., Chaker M., Nafaa R., Fenjiro I., Antari M., Ferreira A., Van Dijck S., 2004, *Dynamique de l'eau et Gestion des terres dans le contexte du changement global, analyse agro-hydrologique dans le bassin du Bouregreg (Maroc),* Sécheresse, 15, 1, 66-77.

Laouina A., Chaker M., Naciri R., Nafaa R., 1992, *L'érosion anthropique en pays méditerranéen, le cas du Maroc septentrional*, Bull. Assoc. des Géogr. Fr., 5, 384-398.

Laouina A., Nafaa R., Chaker M., Naciri R., Coelho C., Ferreira, A., Carvalho, T., Boulet A.K., 2000, *La problématique de la gestion de l'eau et du développement des communautés locales rurales au Maroc,* Mosella, 25, 3-4.

Nafaa R., Laouina A., Watfeh A., 1997, *Occupations des sols et dégradation des terres dans la Mamora*, Méditerranée, 1,2, 45-53.

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