

FOREST AND STEPPE GRAZING LANDS IN MOROCCO DEGRADATION PROCESSES AND IMPACTS ON RUNOFF AND EROSION

The Moroccan environment is characterised by highly diversified ecosystems, hydro-dynamical situations, chains of processes, social conditions and systems of production. Degradation and preservation of lands are important issues since degradation is a real threat and its phenomena are accentuating.

The Mediterranean climate of Morocco is distinguished by an increasing aridity from North to South and from West to East, excepting mountain areas. 39 million hectares are devoted to agriculture, forestry and breeding, i.e. 55% of the national territory. As regards climatic distribution, 78% of the country belong to arid and Saharan areas, and 15% are situated in semi-arid zones. On the whole, soils contain little organic matter and their structure is unstable.

Nearly half the country area is a desert. The remaining half includes 9.2 million hectares of cultivable lands¹, nearly 6 million hectares of forests², 3 million hectares of alfa patches and 21 million hectares of permanent rangelands. The agricultural area has actually been extending, since it covered only 7.8 million hectares in 1980. Such an extension occurred at the expense of grazing lands, of dead lands, and of the limits of forests that have been cleared. Grazing lands have been decreasing from 23 Mha in 1977 to 21 Mha to date. Consequently, there is a parallelism between the decline of grazing lands and the extension of cultivated lands. This is one of the main causes of land degradation. In relation to the number of inhabitants, the UAA tends to decrease since the demographic growth is quicker than the extension of cultivable lands. It is still possible to win lands through land development, but this kind of choice should be considered with the utmost caution, since the clearing of forests or rangelands may entail a quick land degradation³.

Physical conditions allow to define two kinds of areas; in the first one, conditions are favourable, while in the second one, the environment is globally hard but likely to supply productions of interest and a favourable living environment, provided that several precautions are taken in order to use resources in a rational way.

	Million hectares	%
UAA, including:	9.2	13
Favourable bour	2.5	27
Unfavourable bour	5.1	55.5
Irrigated lands	1.6	17.5
Forests	8.8	12.3
Rangelands	21	30
Uncultivated lands	32.1	45
Total	71.1	100%

Table 1 - Land distribution in Morocco

¹ The UAA (Useful Agricultural Area) is concentrated in the semi-arid Atlantid and Mediterranean regions (77% of the national UAA).

² Statistics include forests, alfa and scattered Saharan trees under the same heading, for legal reasons (the national or private status of lands). In fact, the 3 million hectares of alfa, the 1 million hectares of Saharan acacias, and even the 1 million hectares of argan trees should be counted within steppes, because the vegetation cover is widely scattered. Even in many of the remaining forests, the density and height of trees are more characteristic of a matorral than of a genuine forest.

³ In fact, in available statistics, lands that are lost due to soil ablation are not deducted from the UAA, whereas they are becoming unfarmable.

RANGELANDS IN MOROCCO, EXTENSION AND DEGRADATION PROCESS

Breeding accounts for a considerable part of the agricultural GDP (26 to 32% according to the year) and for 20% of agricultural jobs. Regarding the agricultural added value, it ranks second after cereal crops. Its growth over the last 15 years amounts to 5% per year. Livestock includes 3.3 M cattle, 17 M sheep and 5 M goats; these figures vary according to the year and are particularly connected with climatic conditions.

The breeding activity is represented quite all over the national territory. On the whole, it can be said that, out of the 71 Mha of the country, 62 to 65 Mha are rangelands of more or less fodder value (forests, steppes, high meadows, and Saharan lands); but only 21 Mha are permanently grazed. Besides its own production of fodder supplement, a big share of the cultivated areas is used as a grazing land, at least during part of the year.

Rangelands are mainly grazed by small ruminants, according to the traditional extensive breeding practice of a country that rears nursing animals. Extensive breeding has a considerable comparative advantage in regions of steppes and mountains, where improving this activity is the best possible choice to develop and manage resources.

Rangelands show a large biological diversity, with 4,000 plant species registered. This floristic diversity and the seasonal aspect of the vegetation production explain the complementarity between the various pastoral ecosystems. In fact, in order to compensate for the impacts of climatic uncertainties, stockbreeders adapt their strategy of herd management to these phenomena. Several kinds of herd movements are observed, from movements limited to a same region to longer movements between regions. The fraction and tribes entitled to use these collective rangelands regulate the movements and access to pastoral resources.

However, this way of breeding is significantly declining and genuine nomadism has quite completely disappeared. The settling process obviously involves diversified activities and an improved standard of living, but it is often likely to increase the degradation of some overgrazed rangelands. In fact, limited rotations are responsible for the excessive removal of interesting plant species in favour of non-grazed species. Besides, continuous shuffling intensifies land degradation. Lastly, the cultivation of plots whose soil is fragile accelerates the degradation process, which may lead to genuine aspects of desertification. The decrease in the grazing land area (0.6 to 1% per year on an average, over the last thirty years) due to the cultivation of lands that used to be grazing lands, increases the stocking rate on the remaining rangelands. The extension of the UAA is particularly important in case of a good rainy year. A series of dry years entails the abandonment of cultivated lands. The number of animals does not follow a single trend, but on the contrary varies according to climatic conditions, which in turn undergo spatial and temporal variations. A series of good years allows to increase herds, which accentuates pressure. This pressure is even more serious if a dry year occurs, for there is less fodder production. The decrease in the number of animals – which alleviates pressure - only occurs after a series of shortage years. This loss of herd entails serious economic consequences for the populations concerned, who cannot afford to restore their herd as soon as climatic conditions are favourable again, because they have to wait for their family funds to build up again.

Extension and diversity of grazing lands

The main rangelands are located in the arid and semi-arid areas and in the mountains, as well as in the central plateau and its borders.

	Total area	% forest	Forest area	% steppes	Steppe area	% mountain pasture	Mountain pasture area
Steppes and Saharan lands	49,000			100	49,000		
Pre-Saharan steppes	5,700	1	57	99	5,643		
Eastern steppes	5,000	6	300	94	4,700		
Northern Atlas plain steppes	1,300	22	286	78	1,014		
Argan tree area	1,500	47	705	53	795		
Middle Atlas Mountains	1,200	82	984	14	216	4	48
High Atlas Mountains	2,200	92	2,024	4	176	4	88
Rif mountains	900	100	900	0	0		
Central plateau	800	100	800	0	0		
Central Atlantic coast	80	0	0	100	80		
Total	65,390	9,6	6,209	90,2	58,471	0.2	136

Table 2 - Rangeland area per region (in 1,000 ha and %)

However, the definition of environmental types varies according to the publication or the source; unproductive desert areas are sometimes taken into account. Forest grazing areas rise another kind of issue, since all the forests are used as grazing lands, even though their fodder yield highly varies according to the place. For instance, the productivity of a holm oak forest cannot be compared with a reforested single species forest (eucalyptus or pine tree), since these trees are not grazed and, furthermore, since they cause the removal of secondary species (usually enriching ones). Besides, some steppe areas, like alfa patches, are included in the definition of forests as based on the legal status (national or private status).

Type	Climate definition	Area ha	% area	Production (FU/ha) of forest grazing lands	Production (FU/ha) except forests
High mountains		607,900	0.93%		
Humid level	>800 mm	327,600	5.75%	375	300
Sub-humid level	600-800	2,237,150	3.15%	325	275
Semi-arid level	400-600	3,734,560	5.71%	200-225	225
Arid level	100-400	858,100	13.12%	75-125	150
Desert	<100 mm	4,902,150	76.31%		20

Table 3 - Rangeland area in relation to climate types and fodder production (in FU)

Rangeland productivity varies according to climatic conditions and the nature of the vegetation cover. In forest grazing lands, it varies from 375 FU/ha in wet areas to 75 FU/ha in arid regions. The productivity of steppe grazing lands equals the one of forests in semi-arid areas, but is higher in arid regions, where ligneous vegetation is reduced to its simplest expression.

National fodder production ranges from 3,000 to 5,000 MFU/year, according to rainfall; contributions to fodder production are distributed as follows:

- forests (excluding alfa), which cover 5.5 Mha, actually produce 1 to 1.3 billion FU, whereas their production potential amounts to 1.5 billion. This is 11% of the global contribution, and 30% of the natural contribution from rangelands;
- alfa regions cover 3 Mha and yield 286 MFU; they are namely located in eastern Morocco;
- permanent productive steppe grazing lands extend over 21 to 22 Mha, especially over the plateaux of the Atlantic Morocco, dry mountains, pre-Sahara and Sahara, which represent 32% of the national area. They produce about 3 billion FU, i.e. 25% of the overall budget. It is actually necessary to distinguish between permanent productive grazing lands, and poorer grazing lands, that are only occasionally visited by herds. In fact, these poor grazing lands are being substituted to rich grazing lands, once the latter are cultivated and the former become consequently a necessary supplement.

The contribution from cultivated lands should not be neglected. Cereals (barley, corn), fodder crops, crop remains (straw, stubble), by-products of the agribusiness and fallow supply as a whole more than half the FU production. It has been currently recorded that the share of cereals and fodder crops is increasing while the contribution from rangelands tends to decrease.

Distribution varies according to the region. Forest contributions depend on the extension of the most productive forests at the pastoral level: the Atlantic region comes first; there argan trees, thujas and holm oaks play a major role. Then we find respectively the Middle Atlas mountains with holm oaks and cedars, the central High Atlas mountains with holm oaks, thujas and matorral, and lastly, the central plateau covered with a matorral including thujas, junipers and wild olive trees. Alfa contributions mostly concern the eastern region. In spite of the wide extension of non-forest rangelands in southern regions, the highest production takes place in steppes of the eastern, Atlas, and Meseta areas, and in the northern borders of the pre-Saharan region. Agricultural contribution to livestock food depends on agricultural yield, and especially on the amount of stubble, straw and fallow.

Rangeland degradation

In terms of surface, rangelands have been decreasing by 0.6 to 1% per year, in relation to the extension of cultivated areas or degraded or desertified zones⁴. But the total theoretical productivity of these rangelands has evidenced a surprising comparative stability over the last ten years, since their contribution only changed according to climatic conditions, with no actual trend. This means that, despite the decline due to cultivation and to degradation induced by overgrazing, the threshold effect has not been reached as yet. Pastoral productivity is threatened, but this threat is not yet expressed in terms of production.

Such a degradation is caused by various factors:

- irregular rainfall is the first cause. Variation indexes, from a good to a bad year, may reach factor 15 for annual plants, whereas this factor is only 5 for perennials. The percentage of dry years has been increasing for the last two decades, which makes ecosystems more fragile. Torrential rains are also involved, since they cause a lot of damage. These climatic threats are on the whole less fatal for livestock, since fodder supplements allow to reduce the impact of droughts and snow coverage ;
- the mismanagement of rangelands is the most serious threat. The abandonment of rotations is a major cause. Modernisation and the use of considerable financial means are not free from all danger. For instance, lorries may have negative impacts, since they quickly transport herds to areas where it has just rained, and the early arrival of livestock prevents rangelands from regenerating. Cultivation concentrates herds in more and more reduced areas.
- a wrong distribution of watering places explains a more intense degradation in their surroundings.

Considering overgrazing in forest areas, the fact that they are used as grazing lands entails significant consequences. Because of traditions, there are too many animals per herd: consequently, they degrade trees, grass and soils.

The whole forest area is used as a grazing land by the neighbouring populations or usual transhumant shepherds, and in some cases, in spite of legal provisions, by populations who do not belong to the forest area.

⁴ In fact, the permanent grazing land area has been extending because of the more regular use of degraded lands, which were previously visited from time to time; this extension is far from being a positive conquest. Conversely, the global area has been reduced in favour of the UAA, through clearing or cultivation – degradation occurs in those cases as well.

On the whole, the pastoral production of forests in normal years amounts to about 1 to 1.5 billion FU. This figure represents nearly 1/3 of the pastoral fodder contribution. But the forest contribution varies a great deal according to regions and vegetation. Holm oaks, argan trees, cork oaks and alfa provide the highest forest contribution.

The livestock that use forests as grazing lands amounts to more than 10 million heads (5,320,000 sheep, 4,059,000 goats and 732,000 cattle), i.e. 45% of the national livestock. The needs of this livestock amount to about 3.4 billion FU, of which 1.5 billion is supplied by the forest itself, and the rest partly by grasses and the remains of crops in the neighbourhood of forests. Whenever feed supplement is neither actual nor sufficient, forest grazing inevitably leads to a regular degradation that damages the forest capital.

More globally, grazing lands (either forest or steppe lands) cannot meet the needs of livestock as regards fodder. The deficit is more or less acute according to the region, and is more or less made up by fodder supplement. In arid areas, degradation is connected with an excessive stocking rate, that is explained for instance by the existence of a watering place or the fact that the government subsidises fodder, thus encouraging breeders to keep their herd. In less arid areas, human pressure becomes a major degradation factor, because of restricted surfaces (cultivation of the best lands) and of the excessive logging.

	Cattle		Sheep		Goats		Total needs	FU Production	Balance
	Number	Needs in 1000 FU	Number	Needs in 1000 FU	Number	Needs in 1000 FU	1000 FU	1000 FU	1000 FU
Azilal	66,600	79,920	497,800	149,340	503,800	125,950	355,210	238,343	116,867
Beni Mellal	99,600	119,520	510,500	153,150	59,800	14,950	287,620	159,498	128,122
Ben Slimane	52,700	63,240	153,300	45,990	9,400	2,350	111,580	95,000	-16,580
Casablanca	61,400	73,680	119,300	35,790	400	10,0	109,570		109,570
El Jadida	270,800	324,960	396,300	118,890	1,200	30,0	444,150	249,633	194,517
Khouribga	60,800	72,960	553,800	166,140	55,800	13,950	253,050	120,488	132,562
Settat	17,500	210,600	909,100	272,730	55,300	13,825	497,155	56,875	440,280
Al Hoceima	38,100	45,720	55,800	16,740	94,700	23,675	86,135	70,000	-16,135
Boulmane	10,900	13,080	425,600	127,680	93,400	23,350	164,110	152,864	-11,246
Fès	62,700	75,240	206,800	62,040	101,900	25,475	162,755	140,000	-22,755
Taounate	158,300	189,960	209,500	62,850	47,000	11,750	264,560	220,000	-44,560
Taza	101,000	121,200	495,600	148,680	319,800	79,950	349,830	83,276	266,554
Errachidia	32,700	39,240	272,200	81,660	313,600	78,400	199,300	77,071	122,229
Khenifra	49,700	59,640	433,300	129,990	113,200	28,300	217,930	378,579	160,649
Meknès	124,900	149,880	836,500	250,950	39,600	9,900	410,730	320,000	-90,730
Chefchaouen	89,800	107,760	63,900	19,170	187,700	46,925	173,855	97,874	-75,981
Kénitra-Sidikacem	503,500	604,200	1,140,300	342,090	35,100	8,775	955,065	270,994	684,071
Khemisset	190,600	228,720	567,900	170,370	120,300	30,075	429,165	253,137	176,028
Rabat	28,200	33,840	38,100	11,430	1,500	3,75	45,645	41,376	-4,269
Tanger	81,500	97,800	148,200	44,460	62,800	15,700	157,960	28,807	129,153
Tétouan-Larache	164,800	197,760	257,300	77,190	177,400	44,350	319,300	150,480	168,820

Figuig	10,900	13080	478,700	143,610	179,200	44,800	201,490	248,645	47,155
Nador	43,400	52080	484,500	145,350	65,300	16,325	213,755	125,000	-88,755
Oujda	53,400	64080	588,500	176,550	160,400	40,100	280,730	136,508	-14,222
Agadir- Taroudant	142,100	170520	520,600	156,180	677,000	169,250	495,950	281,569	214,381
Guelmim	2,900	3480	23,000	6,900	26,200	6,550	16,930	16,930	0
Ouarzazat	83,600	100,320	672,400	201,720	474,900	118,725	420,765	97,543	323,222
Tata	7,400	8,880	48,800	14,640	74,700	18,675	42,195	17,091	-25,104
Tiznit	59,600	71,520	285,700	85,710	318,500	79,625	236855	73,012	163,843
El Kelaa	1074,00	128,880	656,800	197,040	78,800	19,700	345,20	546,709	201,089
Essaouira	57,800	69,360	285,500	85,650	320,600	80,150	235,160	206,227	-28,933
Marrakech	193,400	232,080	836,400	250,920	444,800	111,200	594,200	311,124	283,076
Safi	138,200	165,840	589,100	176,730	67,200	16,800	359,370	290,044	-69,326
Total	332,420 0	3,989,040	1,376,11 00	4,128,330	528,130 0	1,320,325	9,437,69 5	5,554,697	3,882,99 8

Table 4 - Needs of the Moroccan livestock expressed in FU, FU production, Balance (as per province)

State of degradation of grazing lands

It has been proved that vegetation generally tends to decline; there are some specific cases of positive dynamics, but also fluctuations that are peculiar to each region, and depend on bioclimatic factors as well as on social transformations.

The degradation of the vegetation cover shows the following evolutions:

- on the one hand, the aspect of plant formations is quickly degrading, which is connected with the overexploitation due to the excessive logging of timber and above all of firewood, and with overgrazing. In Morocco, the exploitation of firewood is assessed at three times the actual productivity of forests, on an average. Dense forests are transformed into thin woods that become sparser and sparser, and may even look like a steppe.
- on the other hand, forests are actually declining, due to the encroachment of cultivated plots in their original area. This is how forests today extend over 2/3 only of their initial area of a century ago (Plit, 1983). Land needs explain the trend to use slopes – even steep ones, and these new conquests do not always care for soil preservation. The organic contribution from the vegetation cover (3 to 10 t/ha/year of organic matter) is irreplaceable. Clearings entail that this contribution quickly reduces. Under 1 to 1.5% of organic matter, porosity subsides, therefore decreasing the capacity of storing water.

A regressive dynamics is evidenced by the scarcity of species of appetising quality, a reduced phytomass in relation to its potential, grasses that are extremely sensitive to climate variability and lastly, a very low capacity of vegetation recovery, following a simple enclosure. Inertia affects these ecosystems, and some toxic plants appear.

As far as dynamics are concerned, there are many combinations according to the land and to the farming dynamics. Works by Pascon et al, 1983, showed a close relationship between the extension of surfaces eroded by sheet runoff and the length of time a land has been occupied (based on the approximate date of creation of a *douar*). Soil truncation then seems to have originated a long time ago. Conversely, there are no links between the intensity of use of a land and the density or depth of the gullies that cut it. Their location, their shape and their size are more connected with the geomorphological context, the thickness and nature of superficial formations, the length of the slopes. A succession of climatic events may be another possible explanation in some cases.

Out of the 32 million ha of permanent grazing lands that belong to Morocco (including forests), only 4 million ha are just slightly degraded and yield on an average 90 FU per ha and per year. In grazing lands that are degraded but not highly degraded as yet, the reduction in yield amounts to about 25% and their productivity is

assessed at 68 FU/ha/year on an average. Lastly, 8 million ha are highly degraded; their productivity, reduced by 45%, equals to 50 FU/ha/year.

Region	Surface of grazing land in Mha							Stocking rate of small ruminants
		fD Mha	%	MD Mha	%	FD Mha	%	
Eastern area	5.25	0.696	13.26	0.245	4.67	1.916	36.50	1.6
Middle Atlas mountain	1.21	0	0.00	0.99	81.82	0.223	18.43	0.4
High Atlas mountain	2.26	0.179	7.92	2.028	89.73	0.062	2.74	1.6
Rif mountains	0.91	0	0.00	0.583	64.07	0.333	36.59	0.5
Northern Meseta	0.81	0	0.00	0.81	100.00	0	0.00	
Southern Meseta	1.27	0	0.00	0	0.00	1.27	100.00	0.4
Central Atlantic coast	0.08	0	0.00	0.08	100.00	0	0.00	0.05
Argan tree area	1.46	0	0.00	0.561	38.42	0.798	54.66	
Pre-Sahara	5.66	0	0.00	2.606	46.04	3.714	65.62	1.8
Sahara	46.55	3.407	7.32	43.145	92.69	0	0.00	
Morocco	65.6	4.282	6.54	51.048	77.98	8.316	12.70	

fD: slight degradation; MD: average degradation; FD: high degradation

Table 5 – Stage of degradation of grazing lands

Degradation of grazing lands in watersheds (upstream dams⁵)

As regards runoff and water erosion, the main evolutions are recorded in the upstream areas of watersheds. This analysis is performed at the scale of watersheds, in order to try to find out relationships between degradation intensity and water processes.

Degradation connected with over-logging and clearing

This analysis is based on two elements that cause the natural vegetation cover to decline:

- logging for firewood and assessment of the deficit that allows to reckon the equivalent degraded surface;
- actual clearing of lands for cultivation.

There is obviously a close connection between these figures regarding degradation and the density of population.

⁵ Watershed areas that are located upstream from dams.

Watershed	Dam	Area (km ²)	Forest (ha)	Firewood deficit (m3)	Equivalent cleared surface	Clearing and new cultivation /year	Total degradation
Loukkos	El Makhazine	1,820	74,531	125,900	420	872	1,292
Mharhar	Batouta	180	5,724	29,637	98	53	151
Martil	Nakhla	110	9,584	15,309	51		51
Nekkor	El Khattabi	790	61,016	83,687	279	732	1,011
Moulouya	Mohamed V	49,920	627,000	-83,367		188	188
Sebou	Allal Fassi	5,765					
Ouerrha	El Ouahda	6,153					
Inaouène	Idriss I	3,680	134,912	71,837	239	142	381
Beht	El kansera	4,540	53,395	27,790	93		93
Bou Regreg	Ben Abdellah	9,800	260,572	11,683	39	26	65
Oued el Abid	Bin el Ouidane	6,400	110,632	40,133	134	166	300
Tessaout	My Youssef	1,440	32,600	17,654	59	49	108
Lakhdar	Hassan I	3,680	113,886	13,782	46	171	217
OR Moy	Al Massira	28,500	39,402			12	12
Nfis	Takarkoust	1,710	124,000	29,253	98	74	172
Issen	Abdelmoumen	1,300	47,283	14,641	49	5	54
Massa	Ben Tachfin	3,780	31,556	270,759	903		903
Draa	Mans. Dahbi	15,000	37,000				
Ziz	Hassan Dakhil	4,400					
Total		148,968	1,763,093				
% total country		21%	34%				

Source: PNABV, Eaux et Forêts (Forestry Commission)

Table 6 - Forest degradation upstream from watersheds

Impact of breeding on land degradation in watersheds

The needs of the livestock that grazes in upstream watersheds amount to more than 2,181 MFU (*excluding upstream Ouerrha and Sebou since they were not assessed within the PNABV*). There are actual consequences due to the degradation of the grazing lands, in the places where feed supplement cannot be provided.

Watershed	Area (km ²)	Grazing land area (ha)	Total AUE	Fodder needs in 1,000 FU	Grazing land fodder production in 1,000 FU	Cultivated land fodder production in 1,000 FU	Total	Production/needs
Loukkos	1,820	118,300	101,318	121,581	20,703	55,797	76,500	63%
Mharhar	180	17,800	2,696	3,235	1,558	10,581	12,139	375%
Martil	110	7,566	2,763	3,316	1,615	2,177	3,792	114%
Nekkor	790	19,500	9,711	11,653	1,024	8,259	9,283	80%
Moulouya	49,920	3,269,912	418,658	502,389	185,404	73,758	259,162	52%

Sebou	5,765							
Ouerrha	6,153							
Inaouène	3,680	136,434	154,281	185,138	17,429	73,794	91,223	49%
Beht	4,540	112,432	193,055	231,666	9,202	30,807	40,009	17%
Bou Regreg	9,800	425,859	270,861	325,033	52,168	86,260	138,428	43%
Oued el Abid	6,400		54,804	65,764	12,058	6,965	19,023	29%
Tessaout	1,440	42,600	56,931	68,317	3,728	12,960	16,688	24%
Lakhdar	3,680	121,782	42,961	51,553	10,656	16,440	27,096	53%
Oum Rbia Moy	28,500		171,008	205,210	24,189	188,743	212,932	104%
Nfis	1,710	138,013	95,814	114,977	14,153	38,826	52,979	46%
Issen	1,300	120,066	15,455	18,546	12,607	20,514	33,121	179%
Massa	3,780	225,390	78,436	94,123	24,613	32,894	57,507	61%
Draa	15,000	1,375,240	99,324	119,188	144,400	35,547	179,947	151%
Ziz	4,400	440,000	49,668	59,602	24,948	10,427	35,375	59%
Total	137,050	6,888,212	1,817,744	2,181,291	560,455	704,746	1,265,201	58%

Source: PNABV, Eaux et Forêts (Forestry Commission)

Table 7 - Fodder needs of livestock, fodder production and consequence on watershed balance

The degradation of forest and steppe grazing lands undoubtedly entails considerable impacts on the water balance, infiltration and runoff; besides, animal shuffling very likely plays a part by causing the soil to crumble and making transportation easier. However, close relations between these two phenomena are far from being evidenced as yet in Morocco, and require many field studies.

RUNOFF - WATER EROSION OF SOILS

The relief of the Moroccan mountains is favourable to land degradation and water erosion; its massifs have steep slopes that induce the development of gravity-connected processes. But oddly, runoff acts above all in the middle and lower parts of massifs and on piedmonts.

Lithology is highly diversified. The Rif mountains and its foothills are mainly composed of erodable rocks; there is a huge transportation of material, which greatly contributes to silting up. The Atlas, Meseta and Sahara regions are mainly made up of hard rocks; hence, transportation is low and selective. In these little-eroded environments, the shallow soil is still highly threatened because of the poor vegetation cover. In piedmonts, calcareous crusts protect movable depositions, but gully erosion and the steepness of wadis leave these materials bare; which increases the erosion located in the gashes.

Under forest covers, Moroccan soils are rather resistant and often well structured, since they are rich in limestone or free iron. But, when they are deprived of organic supply, such soils disintegrate and subside; the slaking crust then allows abundant runoff. The steppe cover also plays an important part as regards soil protection; desertification only occurs when this cover is highly degraded.

The Moroccan climate is rather mild on the whole, compared with the climate of tropical or continental temperate regions, excluding some storms that occur in the mountains at the end of the dry season. The maximum intensity within 30 minutes, with a 10-year return period, does not exceed 1 mm/min. However, long winter rains saturate soils and cause peak debits and huge transportation.

The sub-humid and semi-arid oceanic areas are characterised by periods of continuous rains during western disturbances in winter and by a total drought in summer. Runoff is more particularly consecutive to saturation. In this case, degradation is caused by the energy of runoff waters that should be properly managed, by delaying the runoff and scattering energy.

Conversely, the steppe and mountain areas are affected by events of intense and heavily concentrated rains that may occur in the middle of summer. Runoff is an intensity-related phenomenon. 50 mm events of average intensity may entail no consequence, whereas a lower but intense depth of runoff may cause major transformations. Surface

runoff is materialised by a sheet of some centimetres in arid piedmonts, by irregular channels along the slopes, or scratches and furrows.

Rainfall globally determines the depth of runoff, which in Morocco varies from 0 to > 500 mm/year. Combining lithological factors with the depth of runoff enables to draw a map of land fragility.

	Watershed area in km ²	In mm		In billion m ³		
		Pm	Pd	Pm	Pd	Mean surface runoff
Rif (2shorelines)	20,600	680	450	14.008	9.270	4.119
Moulouya	57,500	245	120	14.088	6.900	1.656
Sebou	40,000	750	475	30.000	19.000	5.600
Bou Regreg	20,000	500	335	10.000	6.700	0.830
Oum Rbia	35,000	515	330	18.025	11.550	3.680
Tensift	37,500	330	200	12.375	7.500	1.110
Sous-Massa	35,400	240	140	8.496	4.956	0.701
Southern Atlas	164,190	170	75	27.912	12.314	1.300
Sahara	300,660	50	22	15.033	6.615	0.030
Morocco	710,850	211	115	149.989	81.748	19.026

Pm: mean yearly rainfall, Pd: dry decadal yearly rainfall

Table 8 - Mean dry year rainfall per watershed in mm, rainfall contribution and runoff

The hydrology of Morocco is characterised by an organised network, radiating from a central water reserve, represented by the Rif mountains and the High and Middle Atlas mountains. But Moroccan wadis are often short and rarely exceed 500 km. Their lines are often linear and unstructured; they are the juxtaposition of sections facing different directions. The very high evaporation explains the high deficit and local endoreism that is far from being insignificant and exists even near the coasts. In relation to climatic conditions, particularly to concentrated rains and considerable evaporation, the runoff coefficient is often low; this is why water shortages occur regularly, even in the regions where it rains most.

River accretion widely varies:

- snowy areas, whose recharge is abundant and regular, are located above 1900 m in the Middle Atlas mountains and above 2500 m in the High Atlas mountains;
- in some mountains, despite the slope, a layer of stones favours water infiltration and stabilises stream-flows;
- calcareous massifs provide the best conditions for a regular river recharge, like in the Middle Atlas mountains.

Moroccan wadis may be classified as follows:

- steadily abundant streams, that subside in plains, in summer. The Oum Rbia is an instance of such streams, with a low water level of 34 m³/s;
- streams whose mean discharge is significant, but irregular; this type of pattern applies to most Rif wadis and to the wadis of the Atlantic Morocco;
- -ntermittent streams; such as local wadis in semi-arid plains.

Measurements of the specific land degradation are performed:

- either by studying the river turbidity (DSL in g/l), and computing the solid contributions based on the measurement of the liquid discharge (water contribution in m³);
- either by measuring the amount of silt and estimating the stocking coefficient in the reservoir.

The yearly eroded film is assessed from the estimation of the specific degradation expressed in m³/ha. Taking the scale of the 14 Mha covered by watersheds, the eroded film seems to be negligible. But there is a real issue at the scale of some watersheds, where this removed film is considerable (Loukkos, Mharhar, Martil, Ouerrha). In those watersheds, the degradation of the forest vegetation cover is the highest and the quickest.

Watershed	Dam	Area (ha)	Water contribution (1,000 m ³)	DSL	Solid contribution (1,000 m ³)	Ds m ³ /ha	Film mm/year
Loukkos	El Makhazine	182,000	916,000	5.38	4,928	27.08	2.71
Mharhar	Ibn 'Batouta	18,000	65,340	13	849	47.19	4.72
Martil	Nakhla	11,000	186,000	4.64	863	78.46	7.85
Nekkor	El Khattabi	79,000	88,000	14.06	1,237	15.66	1.57
Moulouya	Mohamed V	4,992,000	915,000	21	19,215	3.85	0.38
Inaouène	Idriss I	368,000	635,000	5.7	3,619	9.84	0.98
Beht	El kansera	454,000	402,000	4.85	1,949	4.29	0.43
Ouerrha	Al Ouahda	619,000	2,980,000	7	20,860	33.70	3.37
Sebou	Allal Fassi	343,000	219,480	5	1,097	3.20	0.32
Bou Regreg	Ben Abdellah	980,000	842,800	3.14	2,646	2.70	0.27
El Abid wadi	Bin el Ouidane	640,000	1,144,000	4.24	4,850	7.58	0.76
Tessaout	My Youssef	144,000	290,000	5.6	1,624	11.28	1.13
Lakhdar	Hassan I	368,000	295,000	16.62	4,902	13.32	1.33
OR Moy	Al Massira	2,850,000	3,440,000	3.61	12,418	4.36	0.44
Nfis	Takarkoust	171,000	163,000	4.53	738	4.32	0.43
Issen	Abdelmoumen	130,000	86,000	3.48	299	2.30	0.23
Massa	Ben Tachfine	378,000	122,000	10.4	1,268	3.36	0.34
Draa	Dahbi	1,500,000	405,000	14.55	5,892	3.93	0.39
Ziz	Dakhil	440,000	154,000	12.28	1,891	4.30	0.43
Total		13,705,000	13,348,620		91,152	6.65	0.67

Table 9 - Stream-flow, turbidity of wadi water, solid contribution and soil losses

As regards water processes, measurements evidence a norm which is little aggressive in Morocco (Heusch, 1970, Debazac and Robert, 1973). But there are some isolated events that deeply disturb the environment and entail total contradictions with the developments performed, since usually men tried to protect themselves from usual little offensive phenomena, with high-cost investments. However, these devices cannot resist at all events which are of high magnitude but seldom occur. This means that the basic risks concern events beyond threshold; e.g. when surface runoff creates deep furrows (Kalman, 1976), when a stable wet land turns into a disturbed and saturated land, or else, when a usually moderated stream-flow becomes torrential and disastrous.

These threshold-exceeding events are often recorded outside rainy seasons, in high mountains and in dry ones. They are caused by intense phenomena that explain disasters in terms of runoff volume, damaged infrastructures and life losses (disasters of Ourika in 1995 or El Hajeb in 1998). Such situations entail reduced impacts downstream, because waters evaporate quickly.

In the northern mountains, same threshold-exceeding events usually happen in the middle of the wet season and are connected with the duration of rainfall events that are responsible of saturation conditions. Damages are as much considerable, in terms of soils, but above all regarding equipment. Moreover, these situations have huge impacts downstream, with the silting of reservoirs or floods in plains. In fact, it is necessary to realise that, for a proper land management, water should come first, and that it would be necessary to try to avoid concentrations and surpluses, to scatter energy, to let infiltrate the amount of water necessary for plants while draining surpluses and therefore making the most of this water whilst preventing degradations. Such considerations highlight the impact of the vegetation cover and of its degradation.

In Morocco, the action of water erosion varies geographically. In specific areas, it definitely transforms the environment; in other places, it seems to have no effect. This applies to large outcrops of coherent, slightly altered rocks. Usually, runoff only damages superficial formations and soft rocks. Besides, the most efficient action of concentrated runoff is located in steep slopes. In piedmonts, manuring in divaguant branches explains the important sheet runoff.

Regionally speaking, erosion is particularly acute in the Rif mountains, for structural, lithological and climatic reasons. In the Atlas mountains, there are slight differences: soft rock depressions are hollowed out, whereas high mountains are affected by more episodic impacts of exceptional events.

The depth of runoff varies between 0 and more than 500 mm; it is lower than 50 mm in the arid mountains, with a 90% evaporation of the rain fallen; in sub-humid environments, the runoff coefficient ranges from 20 to 30%, and the depth of runoff from 200 to 500 mm. The depth of runoff is higher than 500 mm in the most humid massifs of the Rif mountains, and the runoff coefficient ranges from 30 to 50%.

Soil loss greatly varies and the vegetation cover plays a major part. If we compare three small watersheds with similar physical characteristics but whose vegetation cover greatly differs (Heusch, 1970), results speak for themselves:

- in dense oak groves, even in steep slopes, erosion is negligible;
- the behaviour of a forested, half-cleared watershed, shows a moderate erosion;
- conversely, wheat monoculture in a totally cleared watershed triggers off a high erosion.

This means that a matorral landscape cleared in places, with a degraded cover or cultivated plots, does not change basically the behaviour within a watershed.

The threshold of runoff triggering highly varies (Laouina et al., 1993, Chaker, 1997, Laouina and Chaker, 1998); it depends on runoff intensity as well as on previous rains and soil conditions. However, a frequency analysis over several years has shown that this threshold was about a 6 mm rainfall volume in cereal plots, and a 10-15 mm rainfall volume in an only slightly degraded matorral.

According to the analysis of runoff frequency, a depth of runoff higher than 0.1 mm per event occurs in 32-36% of rain events in slopes cultivated with cereals, in 25-28% in fallow lands and in 9% in the holm oak matorral. Summer stormy rains, characterised by their great violence are the cause of the highest runoff volumes; 90% of runoff events higher than 1 mm occurred in dry periods; profiles are not saturated but runoff intensity, soil subsiding and superficial crusting explain the torrential feature of the stream-flow and the damages that follow.

In the Atlantic region, the usual rainfall has only limited impacts (downstream, the low runoff implies that gullies are quite ineffective), except under specific conditions, such as bare slopes or slopes cultivated with weeded crops or planted with eucalyptus. In these sub-humid environments, most high runoffs are preceded by long frontal rains; Heusch (1970) had noticed this fact in the pre-Rif region.

The turbidity of runoff waters is maximum in cultivated lands, whatever the ploughing technique. Only a system of level terraces reduces it significantly, whereas berms only protect from the least aggressive rains. On the other hand, turbidity is minor under the matorral. A non-grazed, non-cultivated fallow land efficiently protects the soil, even in steep slopes. The main difference between bare or recently ploughed fields on the one hand, and eucalyptus groves on the other hand, lies in the turbidity of runoff waters. Under plantations, abundant runoff waters are clear but induce important off-site effects in the gully network.

Globally, soil profiles are truncated and only retained in pockets. Despite this fact, runoff is moderate in mountain slopes (less than 30% of the depth of runoff in all cases, less than 10% in most cases). Specific degradation is usually low. But the dynamics dramatically changes after intense summer rains in semi-arid continental mountains, or after long winter rains in oceanic or Mediterranean sub-humid environments. The generalised runoff entails floods downstream and a high erosion in the hydrographic networks, while furrows are developing in the fields.

Most erosion occurs in the concentrated stream-flow network:

- furrows are seasonal and ploughing reduces them; however, these furrows cause a massive loss of pedologic material, which goes down into gullies (Kalman, 1976);
- gullies undergo changes that are perceptible at the field scale: the vertical profile of some of them is reactivated, other ones are hollowed out after an event. Conversely, other gullies may disappear through lateral extension and closing up due to ploughing on their edges, through the building of thresholds or merely through their filling up with stones when peasants remove them out of their fields. At the scale of an aerial photograph, such changes are minor.

Heusch's estimations (1970) show that slopes are involved only for a little part in the overall erosion during normal years, but when hydraulicity is particularly high, slopes and gullies play a similar part, since field furrows entail a threshold-exceeding event and therefore, a high degradation.

Floods and river-induced erosion

In Morocco, water is drained through watersheds that are organised but not really hierarchical. The hydrological unity of a watershed is only apparent, since a wadi consists of a succession of streams that are not properly connected and which may be intermittent, within an inherited disproportionate valley, made up of spread alluvial sheets including all mixed pebbles, alluvium and sand. But episodically, mere furrows can change into torrents.

Rain water may reach a very high concentration and entail sudden floods (instant discharge higher than 10,000 m³/s in the Sebou; higher than 8,000 m³/s in the Moulouya). In small wadis, figures are even more impressive (e.g. the Lao wadi discharged 1,530 m³/s from a 939 km² watershed, i.e. 1,630 l/s/km²). Nevertheless, floods are the most sudden and devastating in steppe regions. In the strictly Mediterranean area, floods are limited to the low plains such as the Rharb or to small Mediterranean plains.

When floods occur, turbidity is very high. The ration power/load varies a great deal during the flood, in relation to the lateral contributions of water and debris, and to the resistance of the banks and of the slopes that are near the bed. This is how a wadi often reaches its limit of transportation capacity and is continually moving its bed by wearing its banks away, which increases its load. In wider sections, it spreads its coarse load on the convex bank; in gorges, it carries on its load. It behaves like a lava, for instance, after running across outcrops of soft rocks. Consequently, the profile is always precariously balanced.

Such floods entail huge accumulation: in coastal wadis of the Rif region, alluviation lies at the bottom of the bed (Maurer, 1968); fields are flooded and trees are totally covered. Still, the most serious point is the silting of reservoirs, which is another aspect of river action. Dams represent the cornerstone of the agricultural policy in Morocco and are the fundamental basis for an ongoing irrigation, but they are in danger of silting up sooner or later. By way of example, yearly alluviation is assessed at 50 Mm³ in Morocco.

Economic implications of land degradation

The degradation of the natural environment first means a decrease in forest production, in spite of the extension of plantations; it also means the silting up of dam reservoirs, which are the basis of the modern farming economy and urban development. It also entails a number of damages affecting infrastructures, less tourism in the devastated areas, etc. According to estimates, the most important losses concern destruction and the threat that hangs over reservoirs and infrastructures; the loss of farming land only comes second.

Reduction in land capital - Water erosion causes soils to loose fertilisers every year and reduces their thickness. However, it is worth remarking that maximum erosion occurs during years of high hydraulicity, that, on the other hand, are years of record yields and of good vegetation cover in grazing lands.

Damages affecting infrastructures - Decreased capacities of reservoirs - In North Africa, water resources are limited; in Morocco, the volume stored ranges from 10 to 12 km³. The already lost capacity amounts to 1 billion m³, i.e. 10% of the reservoirs volume. The yearly reduction is 50 million m³, i.e. 0.5% of the yearly storage capacity. From the year 2000 onwards, the annual decrease could reach 100 Mm³, then 150 Mm³ as from 2030 (Conseil Supérieur de l'Eau, 1991). Keeping the capacity at its current rate would mean building a 150 Mm³ dam every year.

CONCLUSION

In Morocco, breeding tends to intensify because stalling and feed supplements become necessary, and because the practice of common grazing lands is less and less used. The slightest variations in the conditions of the vegetation coverage may directly trigger runoff. They may also impoverish the surface layer, because runoff waters carry away soil organic matter and fertilisers.

This sensitiveness to erosion varies according to the vegetation cover. Bare lands are usually more favourable to runoff than forest, matorral or steppe lands. In such lands, the intensity of grazing is a modulating factor as well as an element that determines the occurrence of runoff because it induces to pack down and compacts soils.

Even though the vegetation cover cannot always reduce the occurrence of runoff, it still limits its amount. In forest lands, the biological activity which is considerable in the upper layer, entails that soils are less compacted

and consequently, allow a better infiltration of waters. In bare lands, the upper organic soil layer does not exist or is impoverished, and fine particles are swept along downstream, thus making soils dryer and more sensitive to runoff.

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