4.3.

Integrated Water Management at the Landscape Scale: Science Backing Development – a Case Study in Tunisia

Jean Albergel, Jean Collinet, Patrick Zante and Hedi Hamrouni

Section 1.5 has shown the importance in the Mediterranean to address water and soil as interrelated issues. The integrated management of water and soil around the Mediterranean Basin is based on different approaches depending on the country. Between the "no more drop of water to the sea" and the depletion of groundwater or the start of the depletion of fossil aquifers, different choices exist. Based on the example of the national programme of watershed management in Tunisia as a case study, **the present section illustrates how recent scientific achievements can provide concrete solutions for backing and improving the integrated water management at the landscape scale.**

Strategies aimed at increasing availability of water resources as well as limiting floods and reducing the negative effects of soil erosion have evolved towards the design and implementation of a vast programme of small-scale (< 50 km^2) watershed management; a subset of which is used for parallel research aimed at improving knowledge for the further extension of the programme.

What seems to assert itself is the construction of **small dams** as facilities that are not only targeted to the mobilisation of surface water resources (hillside reservoirs), but also for controlling the high floods by protecting – and limiting the silting of – the largest structures downstream. In recent years, Tunisia and Morocco have opted for this solution. In Tunisia, within a project of 1,000 small dams, over 500 have already been built with the following objectives: i) manage the slopes to reduce the loss of agricultural land amounting to 5,200 ha / year; ii) reduce the silting of some 10 major dams downstream, silting which reaches 25 million m^3/year; iii) increase groundwater recharge; iv) mobilise the larger part of the 500 million m^3 lost in sebkrhas (i.e. salted depressions in arid zones) or in the sea; and v) create points of irrigation development.

A hillside reservoir is a lake resulting from the building of a small dam made of earth in the bed of an ephemeral or intermittent river. The dam can reach 10 meters high (always below 15 meters which is the threshold set up by the declaration of the international commission for the large dams) and is equipped with a lateral weir. This weir, slightly consolidated, is used as a fuse in case of very heavy rains. Hillside reservoirs show a high diversity and capacity, ranging from tens of thousands to several hundred thousand cubic meters, while watershed areas vary from a few hectares to several dozen square kilometres.

Table 8. Silting of small dams in 13 hydrological retention lakes with various land covers. Source: Directory – ACTA and IRD Tunis. The figures do not show or express relationships between forest cover and protection against erosion. Farmlands, protect the soils better by using soil and water conservation techniques. The percentage of bare soils in the catchment is not either a solid indicator of solid transport. Bare soils can be developed on marls, very sensitive to erosion, or on rocky material producing very little sediments.

Station	Watershed area	Year Const.	volume Silt 96	Life span	Vol. Export.	Total Erosion	Spec. Erosion	Vegetation %		
	ha		103 m³	years	103 t	103 t	t/ha/year	Forest	Cultivated lands	Bare lands
Sadine 1	384.0	1988	31.2	9	4.7	54.8	17.8	0	68	32
Fidh Ali	412.5	1991	29,6	23	0	47.4	23.0	0	12	88
M'Richet el Anse	158.0	1991	5	42	0	8	10.1	0	92	8
El Gouazine	1,810.0	1990	16.8	83	1.4	28.3	2.6	20	65	15
Hadada	469.0	1992	14	24	1.3	23.8	12.7	0	76	24
Janet	521.0	1992	36	11	3.5	61.1	29.3	0	62	38
Dekikira	307.0	1991	21	51	0	34.1	22.2	33	35	42
Es Senega	363.0	1991	12	36	0.4	19.3	10.6	0	34	66
Arara	708.0	1993	41	7	4.1	70 .1	33.0	59	41	0
Saadine	272.0	1992	27	7	6.6	50.3	46.3	30	70	0
Es Seghir	431.0	1992	2	>100	0	3.2	1.9	20	80	0
Kemech	245.5	1993	11.4	38	10	28 2	38.3	0	75	25
Brahim Zaher	464.4	1992	14.4	24	0.2	23.1	12.5	30	27	43

Since 1995, twenty-six of them have been selected and equipped to build a network of observatory sites for hydrology in order to evaluate their silting and thus their life span and overall erosion of the basin (Table 8).

Experiments (rain simulation) and modelling on runoff, water stocks and soil loss from slopes have been carried out. They allow advocating for and implementing conservation and management measures at the catchment scale, based on a sound scientific basis.

Knowledge based on the calculation of useful water soil reserves (UR) allows: i) simulating various results for annual rainfall; ii) comparing the soil water storage capacity of catchments with those of retention (dams), and iii) simulating irrigation requirements in relation to various plant covers. Finally, it provides tools for balancing between green and blue water.

The water storage capacity was first estimated from climatic parameters for soils with hydro-physical characteristics assumed to be homogeneous at a constant depth. Subsequently, a better assessment of the Total Available Water (TAW) was approached through a coefficient of utilisation of these reserves by a plant whose root system development allowed for a progressive use of 100 cm of loose soil. Using the soil depth (thickness) accessible to the roots is already a relevant step forward. However, it neither gives information on the physical characteristics of materials that can control accessibility and the volume of necessary reserves, nor on the possibilities of capillary rise from a deeper aquifer. An example of the methods used to overcome these difficulties is presented in Box 15, Table 9 and Figure 45.

Box 15. Water useful reserves computation in the Zanfour basin

Soil maps at the basin level and the implementation of a GIS were used to build and spatialize this hydro physical information. The Zanfour basin, which has an area of 42 km² and a reservoir of 710,000 m3, is part of the pilot Tunisian watershed network. It was therefore interesting to calculate the TAW, simulate various results for annual rainfall, compare the water capacity of soil in the catchments with those of retention and to simulate irrigation requirements in relation to all types of cover.
The depths, textures and coarse loads are extracted from the soil map, while critical soil moisture thresholds with potentials of 2.5 for FC (Field Capacity) and 4.2 for WP (Wilting Point) are calculated by the method of A. Bruand et al. (2002). A GIS (ArcView) was implemented to link soil units to the variations of depth, texture, coarse elements, humidity at FC and WP, and finally compute TAW isolines and draw the TAW map (Figure 42). Among all possible simulations we retain:

- **A simulation of a partial filling of TAW of soils in the basin**
  In 2001, with a rainfall of 350 mm, the rate of filling the soil reserves was obtained by cumulating annually the volumes of different classes. The partial filling of useful water reserves of all soils in the watershed provides watershed storage of 1.4 million m3 (Table 9) representing two times the capacity of the reservoir.

- **A simulation of the saturation of the whole TAW of the soil in the basin**
  The comparison of unsaturated reserves of 2001 with saturated reserves allows for the establishment of reduction coefficients in column 4 of Table 9.

The complete filling of water reserves of all soils of the basin provides storage of 2.2 million m3 representing three times the capacity of the dam's reservoir. With this stock and the results of 2001 (Annual Rainfall: P 350mm, Crop Reference Evapotranspiration ETo: 1,896 mm), it was possible to compute the theoretical annual rainfall allowing to completely fill the soils' water reserves. It should reach 553 mm, to be compared with the mean annual rainfall on Zanfour Basin: 400 mm.

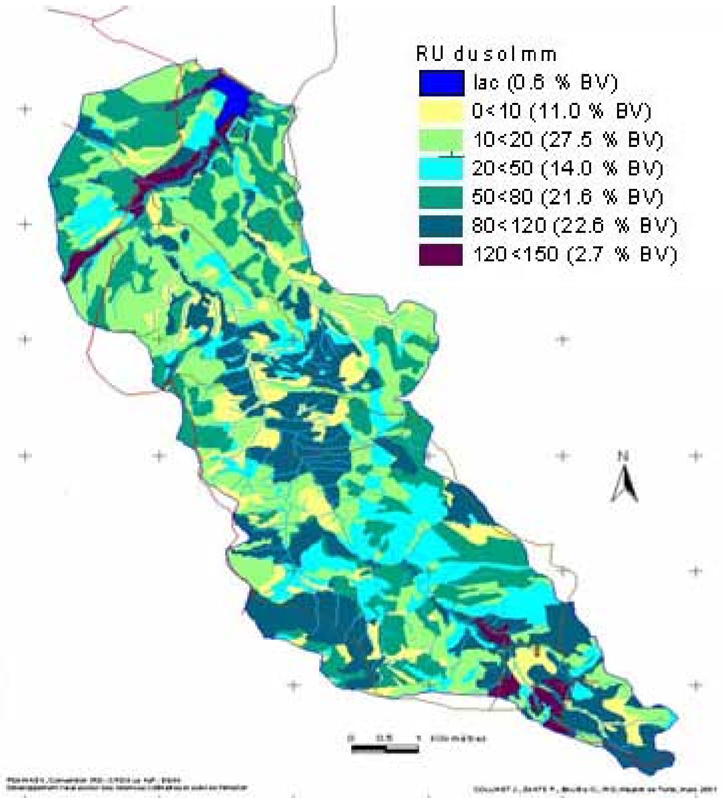

Figure 45. Map of isolines of soil usable water reserves UR. Source: Collinet et al. 2001.

Table 9. Water reserves of the basin for total and partial soil saturation.

Average UR per class (mm)	Area of each class (ha)	Total saturation UR x area (103.m^3)	Reduction Coef. Stock /P cum.	Filling 2001 UR x area x coef. (103.m^3)
5	481	24	0.29	7
15	1,202	180	0.51	92
35	609	213	0.63	134
65	943	613	0.65	398
100	988	988	0.65	642
135	117	158	0.65	103
total	4,340	2,176		1,376

The results show the usefulness of the methods which provide valuable quantitative and spatial data for water management in the watershed, in particular regarding rain-fed and irrigated crops in relation to rainfall and stored water in the dam, and thus balancing between green and blue water

The effects of changing the vegetation cover, including forest, and of soil and water conservation techniques can be predicted on the basis of the calculation of sheet and gully erosion, and the use of simulation techniques.

In the following paragraphs, three examples of how scientific progresses can back watershed management in relation to soil erosion are presented. They have been obtained through research on the Abdessadok basin, which was established with the following characteristics: 307 ha, a reservoir with an initial capacity of 92,500 m^3, a current capacity (2001) of 65,000 m^3 due to specific silting of 10.6 m^3/ha/year and 50% of the basin being used for farming (low yield cereal growing + extensive sheep rearing on steep land).

a) The erosion of the slopes associated with differences in the use of the basin has been analysed and quantified either on experimental plots or at the basin scale. The large scale analysis of behaviours (plot) has allowed for the understanding of the phenomenon on a small scale (basin) and, in particular, to distinguish the transition from areolar erosion and linear erosion then to gullying. Statistical models such as RUSLE 2 (revised universal soil loss equation-version 2) of G.R. Foster, allow applications on slopes with complex geometry. They were implemented and combined with GIS on different basins of Tunisia (see Box 16). The results have been compared to the silting up of the hill reservoir. They show that the methods used for simulating soil erosion are consistent with actual observations, and can provide valuable data for further improving land-use and agricultural techniques.
b) The vegetation cover influences water and erosion processes (see chapter 1 and 2). Therefore, when designing plans for watershed management, it is important to be able to predict the consequences on erosion of using certain ground cover types in some parts of the watershed. As experimenting would be a long process (in particular, in the case of planting a new forest!), sound modelling

Box 16. Erosion calculation since the dam construction (1993 to 2001)

The model has given the following overall erosions:

a) 1.75 t / ha / year in a dry year which has been computed with a rain index Rsi = 25 MJ.mm / ha.h

b) 4.12 t / ha / year in median year with Rsi = 64 MJ.mm / ha.h,

c) 6.03 t / ha / year in wet years with Rsi = 93 MJ.mm / ha.h.

It appears that the exceptional occurrences of heavy storms (above 50 mm per day with high intensities, above 90 mm/h during 5 minutes) highly affect to these estimates calculated over long periods. It is thus that 1994–95 was a particularly aggressive year with annual rain index computed on 276 rain episodes (intensity calculated on 30 minutes) with 219 rain episodes during October 1994, a period of high soil vulnerability due to ploughing: the calculation of the overall erosion, weighted by the area and a bare soil index (C = 1) during the ploughing season, gives 22.5 t / ha / year which is enough to explain the previous silting up.

Box 17. Simulation of reforestation with Aleppo pine of upstream scrubland on stony limestone soils (lithosols)

The first simulation focused on the reforestation of the current scrubland area of the steep foothills (slope >25%) with stony and shallow soils (lithosols on soil unit 3 and regosols on soil unit 7). Instead of waiting 20 years for a forest stand to grow to observe an improved overall protection of the basin, the simulation allowed to detect an increased protection by some 12% (Figure 45). Other factors should also be considered, such as the improvement of water reserves (as observed on the Zanfour Basin), the availability of timber and firewood – essential goods for the farming community in the basin as well as benefits related to reduced erosion.

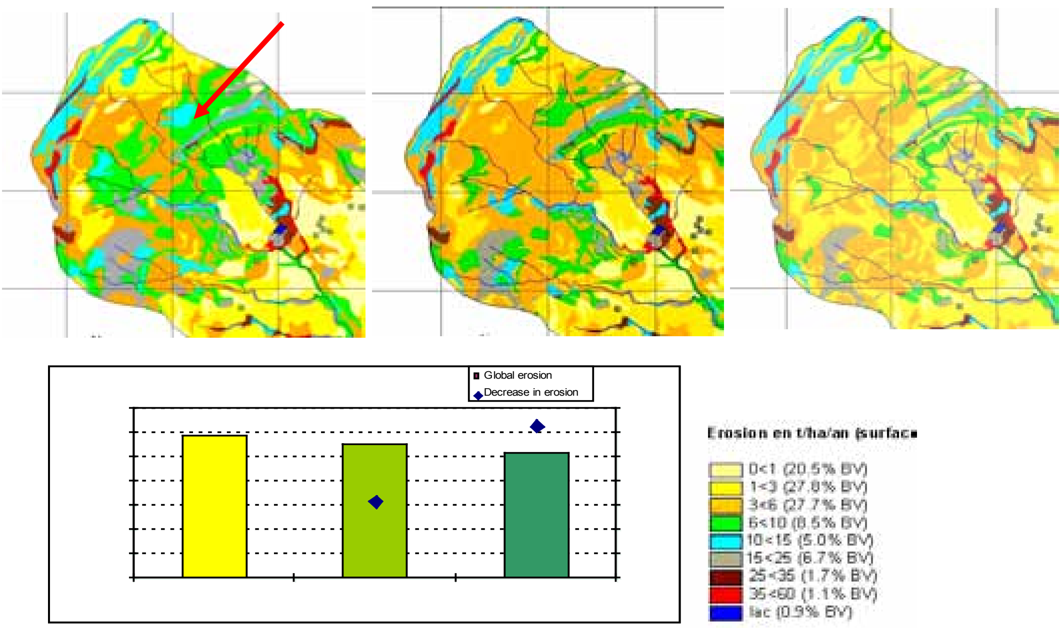

Figure 46. The Abdessadok Basin (partial), limiting erosion with the replacement of scrubland (left) on upstream lihosols by a young forest (center) becoming a mature adult (right).

Box 18. Simulation of the removal of terracing benches

This simulation analysed the effects of the total removal of the terracing benches on both sides of the river. This removal would increase by 30% the overall erosion of the basin (Figure 47). By only removing the benches on the right bank or only on the left bank, it was shown that their protective effects varied significantly depending on the banks: the right bank appeared more fragile as the bare soils occupy a greater area and slopes are steeper.

techniques can offer excellent alternatives. On the same Abdessadok basin, such methods have been successfully applied as presented in Box 17. The results show that substituting some units' shrubby vegetation with planted stands of Aleppo pine would effectively reduce soil losses and dam siltation, in addition to the provision of other goods.

c) In addition to dams, watershed management often includes bench-terracing for the retention of water and soil on both banks of the river as it flows through the cultivated glacis. Modelling techniques may simulate the absence or the removal of such equipments. Some data regarding simulations carried out in the Abdessadok basin are presented in Box 18. They show that while benches play a significant role in reducing erosion, their protective efficiency differs in relation to soil and land cover.

It is better to keep one's critical sense on a model that is more statistically than physically based. The used model presents several multiplicative terms which do not account for the non-linearity between factors, but the fact remains that the calculations of erosion resulted in four previous studies of basins of equivalent areas produce results consistent with those measured by bathymetry in the hill reservoirs. This consistency is probably due to the fact that the sediment produced on the different segments of slopes are fully transmitted to the outlet, without intermediate sedimentation – since the slopes are short and generally very steep, the water flows keep their carrying capacity, given their speed and thinness of the transported elements. Within the characteristics listed above, the estimate of overall erosion calculated by weighting is also a reasonable hypothesis. The simulations finally give a proper assessment of the effects of any proposed changes

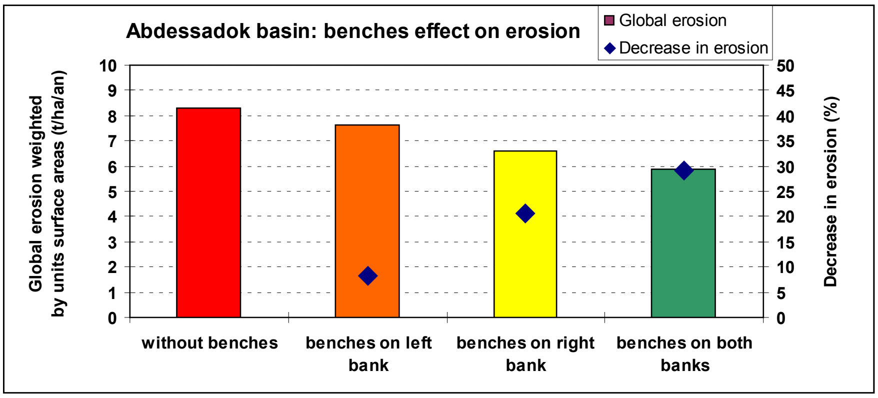

Figure 47. The Abdessadok basin: changing erosions with the partial and total removal of the terracing benches in the downstream area of the basin.

including reforestation, to be carried out when relevant in areas with proper water reserves for the successful establishment of young seedlings. One specific case not covered in the reported studies, concerns basins that are partially or wholly on marl, and that are thus particularly susceptible to gullying. In such conditions, erosion can be between 10 and 100 times heavier than sheet erosions calculated in previous models.

Recommended reading

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What Science Can Tell Us

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– A Challenging Balance

Yves Birot, Carlos Gracia and Marc Palahí (editors)

What Science Can Tell Us 1
2011

What Science Can Tell Us

Marc Palahí, Editor-In-Chief
Minna Korhonen, Managing Editor
The editorial office can be contacted at *publications@efi.int*

Layout: Kopijyvä Oy / Janne Kuivalainen
Printing: Kopijyvä Oy

ISBN: 978-952-5453-79-9 (printed)
ISBN: 978-952-5453-80-5 (pdf)

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