EROSION, SOLID TRANSPORT AND SEDIMENTATION

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ABSTRACT

Erosion is one fo the main problems of the end of this century specially in arid countries.

After investigating factors of erosion and solide discharge (Climate, water, soils, topography, vegetation, human action ...) some observed values of erosion and solid transport are given specially for arid countries but also in other climates for comparison.

Results of those phenomena are indicated before examining the possible palliatives which are always difficult to apply because it is necessary to obtain participation of the population.

EROSION, SOLID DISCHARGE AND SEDIMENTATION IN ARID COUNTRIES

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Arid and semi-arids countries spread over very large areas upon the earth in all continents.

In addition to the chronic lack of water of theese countries there are the catastrophic effects of erosion and solid discharge. We propose hereafter some ideas and some values about those phenomena.

1. *EROSION AND SOLID TRANSPORT FACTORS.*

There is no doubt that water is the main factor. First it is the transformation of its potential energy in kinetic energy (falling of rain-drops from the clouds to the soil, then water run along the slopes and river discharge) which produce erosion and solid discharge.

Indirect factor also since water is necessary for vegetation growth which covers and protects soils, and also promotes biological activity in soils modifying their permeability.

Others important factors are essentially the kind of soils and rocks, the kind or vegetation, the inclination of the slopes and of the river beds, kind and repartition of the rainfalls, wind speed (wind erosion).

The last factor but not the least in human action on landscapes which, by the intense modifications brought to the ecosystems can multiply by ten or even one hundred sometimes the effects observed in natural landscapes.

1.1. Water.

It is obvious that water is necessary to induce erosion and solid discharge. It means that a perfectly dry region would not be eroded at all except perhaps by wind erosion.

Mean erosion and solid discharge are increasing functions of the annual rain fall, everything else being the same. We insist on the fact that we speak here of interannual mean values, as those that can be measured with the sedimentation of the reservoirs behind dams for example.

For annual events or even for a single flood it is possible that tremendous phenomena could be observed. This can happen because in arid countries limit of the overland flow is not often reached and a little increase of the rain over the limit can induce a very important flood. Another particularity of arid countries is that for not too long recurrence (10 or 20 years for example) the area submitted to erosion during one rainfall is not very large. It is only rainfalls of higher recurrence that will produce generalized floods with high discharges on a whole large basin. Consequently solid transolid transport brought by tributaries stays in the main channel for several years. The large flood with a fifty-years or one hundred-years frequency sweeps away those deposits and solid transport in very important. For example series of large floods occured in 1969 on the Zeroud at Sidi Saad (Tunisia) with a very high annual discharge (2,5.$10^9 m^3$ to be compare with the median annual discharge which is only 75.$10^6 m^3$). Consequently a very important solid discharge was oberved : about 250.$10^6 m^3$ for 8950 km2 basin, that is to say approximatively 50 000 t/km2 in one year. But the mean interannual discharge is only between 2000 et 2500 T/ km2 . year. Howewer a series of floods similar to those of 1969 would fill up the dead water of the Sidi Saad new dam in a single year. After such an event dam would be submitted to a gradual lost of its available storage capacity which has been designed to protect Kairouan plain from dangerous floods.

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In the south part of the same country we have observed (1973) on Zita, a little non-permanent river with a 3,2 km2 basin, a single day erosion of 7 mm of soil for a 300 mm rain in 17 hours (2 mm came from the slopes, 5 mm from the channels and banks (for information the mean annual rainfall in only 170 mm ...). It is equivalent to an erosion of 11 000 t/km2.

This erosion rate can be compared with what we observed (1981) in Cabo verde Islands. Ribeira Brava, a little non-permanent river of Sao Nicolao island with about a 6 km2 basin, has carried in two floods in a single month 11 500 t/km2.

In brief the mean interannual rate of erosion and solid transport increases when the mean interannual value of the rainfalls is increasing, everything else being the same. On the other hand generally suspended load decreases. In a way the suspended load measures the efficiency of the work of water for erosion.

Generally water promote vegetation growth and this is an opposite effect for erosion since vegetation protects soils from it. This partly explains the decreasing suspended load when rainfalls increase. Biological activity is also developping with vegetation. This activity increases generally soil permeability and reduces sheet flow. Particulary, when vegetation is missing, it is possible that the surface of soil may be sealed by the wash of fines or arrangements of particles. It is what we call "O.P.S." that is to say in French "organisation pelliculaire de surface" ou "couche de battance". These "O.P.S." much reduce infiltration. Their importance decreases with the increase of the annual rainfall. Hence a maximum erosion can be observed at a certain rate of annual rainfall P_0 (fig. 1).

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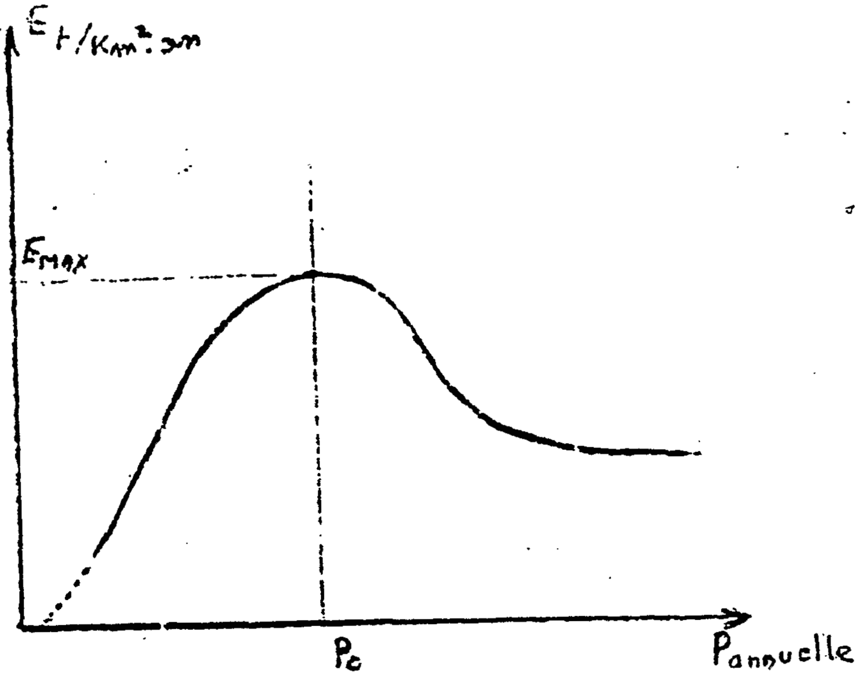

Fig 1 Erosion as a function of mean interannual rainfall

P_o varies between 400 and 700 mm as a function of other factors (soil, kind of vegetation, dimension of the basin).

1.2. Other factors

1.2.1. Soils

Soils, specially by their structure are more or less sensitive to erosion and more or less favourable to the vegetation. Kind of soil can make erosion varies from 1 to 20 (roks except).

1.2.2. Rocks

Besides the fact that soils originate from rocks if large area are covered with not much permeable rocks or with gravel, erosion will be less important.

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1.2.3. Vegetation

Vegetation, the growing of wich depends on water, soils and climate, strongly contribute to the diminution of erosion. The effect much depends on the kind of vegetation. It must be noted that a complete vegetal cover, whatever it may be, is a very effective factor to limit erosion, even with a high inclination of the slopes. Human perturbation in this cover often induces strongly enlarge erosion.

1.2.4. Slopes

On an average erosion increases as an exponential function of the inclination ofthe slope but exponent much varies according to the nature of soils, of vegetation and with the length ot the slope. Solid discharge in channels depends on the water speed and therefore on the inclination of the bed. Particles size are also important.

1.2.5. Rainfalls

According to the climate rainfalls can occur from time to time with discrete hazard repartition (for the driest climate) or concentrated on a short period (2 to 4 months) or a longer period (5 to 8 months). The more the rainfalls have a discrete repartition or a short rainy season the less vegetation can grow normally. Rainfall intensity is also important specially the thirty minutes intensity.

1.2.6. Wind erosion

Far from being negligible, wind erosion often produce in arid countries what is called "desertisation", with no necessity to put forward any climate modification,this could be proved for example in south Tunisia where the necessity of finding wood for cooking and the cattle pressure (sheeps) on the vegetation induce the complete destruction of the natural vegetation (even the roots !), leaving bare soil exposed to wind erosion.

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Wind sweepsaway the fertile part of the soil and leavesa steril matter. This evolution is unhappily practivally irreversible. A too heavy mechanization of agriculture can have the same effect.

1.2.7. Man influence

We have seen above that human work can cause wind erosion. Generally man, by his work, is often responsible of increased erosion and solid discharge. We can mention :

- Wood consumption (or vegetation-) for warming and cooking
- Charcoal making (for the same use that above)
- Crafts or industrial use of vegetation
- Overgrazing of cattles
- Clearing for cultivation
- Building of tracks and roads which often produce gully erosion and soil creep
- Building of anti erosion works on inadapted lands (marl for example). The remede can be worse than the disease.

2. *IMPORTANCE OF EROSION AND SOLID DISCHARGE.*

It is possible to give some values observed in several countries for suspended solid.

Name of the river	*Catchment area (km2)*	*Erosion (t/km2 year)*
Romanche (France)	254	550
Durance at Serre-Ponçon (France)	3 600	625
Durance at Cadarache (France)	12 000	292 before hydraulic management 63 after hydraulic management

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Name of the river	*Catchment area (km2)*	*Erosion (t/km2 year)*
Rhone at Pougny (France)	10 320	50
Medjerdah at Ghardimaou (Tunisia)	1 480	2 000
Medherdah at Bou Salem (Tunisia)	16 230	737
Medjerdah at Medjezel Bab (Tunisia)	21 200	850
Mellegue at Nebeur (Tunisia)	10 300	695 *
Kasseb at Dam (Tunisia)	101	5 070 *
Nebaanah (at Dam) (Tunisia)	855	2 300 *
Zeroud at Sidi Saad (Tunisia)	8 950	2 300 *
Tsanaga at Bogo (Cameroun)	1 535	200
Sanaga at Nachtigal (Cameroun)	77 000	30
Mangoky at Banians (Madagascar)	54 000	200

* Total solid discharge (with bed load)

The lowest values do not correspond to arid countries. All of them are mean interannual values but paroxysms can be far more important and, in this case, mean values are not really significant.

We can mention some paroxyms :

River	*Catchment area (km2)*	*Erosion t/km2 year*	*Mean Value*
Zeroud at Sidi Saad (Tunisia)	8 950	50 000 * (1969)	2 300
Mellegue at Nebeur (Tunisia)	10 300	1 820 * (1969)	695
Oued Zita (Tunisia)	3,2	10 500 (1973)	?
Ribeira Grande at Vila (Cabo Verde)	6	11 500 (1981)	?

* Total solid discharge with bed load

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As for suspended load it is possible to observe values from less than 1 mg/l to more than 500 g/l.

Sedimentation in flood plains can be very important also. In 1973 Medjerdah's deposits (Tunisia) spread over 473 km2 with a total volume of 46.10^6 m3 with depths from some millimeters to 2 meters, the more frequent depths being berween 10 and 15 cm in some days only.

Erosion and solid discharge can be a continuous action when agressive rainfalls are not too rare, or, on the contrary, they can completely modify the landscape in rare opportunities.

Consequently measures are difficult in arid countries where perhaps even long series of observations will not permit to observe the "major" event far more important than the ordinary events.

For the Zeroud at Sidi Saad in Tunisia, design flood was supposed to be 9 000 m3/s until 1959 then in 1962 it was said to be 11000 m3/s after some more observations. Finally, after the major floods of 1969 wich were measured until 17 000 m3/s, design flood climbed up to 30 000 m3/s and the dam was design with this value. Naturally solid discharge was much more that all what you can imagine.

Mean interannual solid discharge can be estimated by formula like the Fournier's formula for great basins or Wischmeyer's equation for little surfaces.

The Fournier's Formula is

$$E = \frac{1}{36} \left(\frac{P_x^2}{P_a}\right)^{2,65} \left(\frac{H^2}{S}\right)^{0,46}$$ (suspended solid and bed load)

were E is the mean annual solid discharge in T/km2 year,

P_x the mean rainfall of the most rainy month in the year,

P_a the mean annual rainfall (mm),

H the mean difference of altitude of the basin

S catchment area in km2

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But this formula is not very good for little basins because of the importance of the particularities on a little aera.
In this case Wischmeyer formula can be tried, but it needs a regional adaptation. Wischmeyer formula is :

A = R. K. SL. C. P.

where A in erosion, R is agressivity parameter depending on maximum rainfall intensity in 30 minutes and on kinetic energy of rain, SL is a topographic parameter (composed with slope and length), K is erodibility character of soil, C is a vegetation and agricultural pactice parameter, P is an anti erosion works parameter.
Unhappily in arid countries these two formula are often quite ineffectual.

3. THE EFFECTS.

3.1. Erosion effects

One can say that erosion has always a bad effect on the ecosystems :

- The best part of the soils is swept away (organic matter in solid discharge is often four or five time the organic matter of soils)
- Creation of a gully erosion that can go until "bad-lands" which are definitively no more useful
- Destruction of roads, bridges, railways and even houses
- Land slides
- Destruction of anti erosion works and so on ...

3.2. Solid discharge effects

It is possible to find good effects of solide discharge. If available storage capacity of dams is progressively lowered by sedimentation of the reservoir sometimes quicker than the designer hoped, if deposits in flood plains make the river wandering until on one hundred kilometers sometimes, if barren deposits can destroy crops, on another side it is possible that it cause in other places fertilization of flood plains.

Almost always the thin sediments (clay and loam) are good for the plankton which is the beginning of biological cycle in the sea. But they can also produce sanding and silting of the harbours ...

4. *PALLIATIVES.*

Struggle against erosion is necessary but it is very difficult. Several kinds of actions are possible.

4.1. Land agricultural reclamations

4.1.1. Vegetation protection

Protection of vegetation against man and cattle allows its growth, covering and fixing soils while seepage is favoured. Theory is easy but practice is more difficult because a strong psychological action on population, a diminution of the cattle and supplying of substitution means for cooking and heating are necessary.

Howewer it is the best possibility for struggle agains desertisation. New vegetation can also be introduced.

4.1.2. Forest developping

Developping new forests when possible is specially efficient. But it also limits sheet flow and consequently available water for small or mean rainfalls. Strong rainfalls only give a high discharge in this case.

It is necessary to avoid the risk of water penury and a good balance must be found.

Some kinds of trees largely used are true water pump : Eucalyptus for example whose wood is not much interesting are often more noxious than useful in arid countries.

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4.1.3. Agricultural techniques

Impossible to say here all what is possible but, incessantly some easy proceedings must be reminded :

- To cultivate along contour lines and not along the slope.

- Utilisation of mulsh, of vegetation panels along contour lines, of agricultural engines adapted to soil and climate. Some ancient techniquesare very interesting though all what is ancient is not necessarily good with news conditions !

Industrial crops like pea-nuts or cotton, so much useful for the economy of developping countries, must be managed cautiously in order not to destroy soil equilibrium.

4.1.4. Anti erosion works

Often very efficient those works are sometimes dangerous when they are not well designed.

4.1.5. Hydraulic works

Erosion in channels much increases with discharge and all that can limit discharge is useful.
Besides field works as above whichreduces overland flow it can be suitable to built dams to limit peak flow.

5. *CONCLUSIONS.*

As a conclusion we can say that, if erosion and solid discharge can be important under every climate, the phenomena are far more intense in arid countries. It is not easy to estimate those phenomena, not only because measures are scarce and difficult but also because arid climate are generally quite irregular with alternate long dry periods and wet periods.
To be efficient fight againt erosion must concern works of every day and not only spectacular designs.