Modelling of suspended riverine sediment fluxes at global, regional and locals scales: major controls, anthropogenic perturbations and associated pollutant fluxes from land to sea

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Modelling of riverine sediment fluxes

- Purpose
  - Pollutant fluxes
  - Temporal variability
  - Anthropogenic impacts
  - Natural controls

- Scale
  - Large
  - Small

- Regions
  - Med Sea
  - GoL
  - Tet, Rhone

- Global
Modelling the atmospheric $CO_2$ consumption by continental erosion

my PhD, about 25 yrs ago ...

DOC: dissolved organic carbon

POC: particulate organic carbon

DIC: dissolved inorganic carbon
In order to predict particulate matter fluxes, one has to predict the vector of these fluxes:

Total suspended solids (TSS)
...bad news: TSS fluxes (FTSS) are highly variable
What globally controls river sediment fluxes?

Climate?

... or morphology/tectonics?

Model of Pinet and Souriau (1988)

\[ Ds = 419 \times 10^{-6} \times Elev - 0.245 \] \quad young orogenes

\[ Ds = 61 \times 10^{-6} \times Elev \] \quad old orogenes

Ds = denudation rates (m/ka); Elev = mean elevation (m)

according to Milliman and Meade (1983), up to 70% of global fluxes (Himalayan faulting!)
Correlation matrix for TSS fluxes and environmental characteristics
Boreal climates
(Slope x Q x LithMI)

Wet temperate
(Slope x Four)

Wet tropical
(Four x Slope x Q x LithMI)

Arid climates *
(Four x Slope x Q x LithMI)

* corrected for contributions from wet climates
Spatial variability of riverine sediment yields

27% of the continental area, but 70% of the total sediment flux is less than 250 Ma.

Ludwig and Probst, 1998
River sediment yields (specific fluxes) result from a combination of hydroclimatic, morphological and lithological factors.

In young orogenes they often combine to high flux conditions, but orogeny itself is not a major control.
Modelling of riverine sediment fluxes

- Purpose: pollutant fluxes, temporal variability, anthropogenic impacts, natural controls
- Scale: large, small
- Mediterranean Sea (Med Sea), Golfe de Lion (GoL), Tet, Rhone

Natural controls play a significant role in understanding the temporal variability and anthropogenic impacts on riverine sediment fluxes.
Why to focus on the Mediterranean?

- The Mediterranean region is a hot-spot area for global change with increasing anthropogenic pressure on water resources => river damming!

- Small mountain rivers are numerous in this area, which could be hot-spots for TSS fluxes

 According to Milliman and Syvitski (1992), these rivers might considerably increase the global budgets.
Mediterranean drainage basins for which mean long-term estimates exist in the literature

Sadaoui et al., 2017
Observed river sediment fluxes (t km\(^{-2}\) yr\(^{-1}\))

Modelled river sediment fluxes (t km\(^{-2}\) yr\(^{-1}\))

FTSS = \(-3668.51 + 0.12Q + 270.79\) Slope + 33.67 SRe + 19.14 Er

% of sedimentary rocks > 600m altitude

% of shrub land, grasslands and agriculture land use types

\(r^2 = 0.91\)

n = 74
Spatial variability of natural riverine sediment yields

FTSS (t km\(^{-2}\) yr\(^{-1}\))

FTSS-nat (Mt yr\(^{-1}\))
FTSS-nat (t km\(^{-2}\) yr\(^{-1}\))

<table>
<thead>
<tr>
<th>Region</th>
<th>FTSS-nat</th>
<th>FTSS-nat</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB Med</td>
<td>997</td>
<td>211</td>
</tr>
<tr>
<td>DB Med (no Nile)</td>
<td>870</td>
<td>493</td>
</tr>
</tbody>
</table>

Sadaoui et al., 2017
(Large) reservoirs in the Mediterranean drainage basin (source: DB GranD, reference year: 2003)

(for sediment retention behind dams, see Vörösmarty et al., 1997)

<table>
<thead>
<tr>
<th></th>
<th>FTSS-ant (Mt yr⁻¹)</th>
<th>FTSS-ant (t km⁻² yr⁻¹)</th>
<th>Ret (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB Med</td>
<td>649</td>
<td>137</td>
<td>35</td>
</tr>
<tr>
<td>DB Med (no Nile)</td>
<td>642</td>
<td>364</td>
<td>26</td>
</tr>
</tbody>
</table>
Data mining for additional dams in the Maghreb region

\[ n = 450, \text{ FTSS retention} = 63\% \]

(DB GranD: \( n = 53 \), FTSS retention = 36\%)

Sadaoui et al., ready for submission
The role of « coastal rivers » in the natural FTSS budgets

large rivers : $> 50 \times 10^3 \text{ km}^2$
$24\%$ of total area*

intermediate rivers
$38\%$ of total area*

58% of FTSS

coastal rivers : $< 5 \times 10^3 \text{ km}^2$
$38\%$ of total area*
(*without Nile)
Mediterranean rivers have in general high natural sediment yields.

But actual river damming considerably reduced the particulate matter fluxes to the Med Sea (probably by ≥ 50%).

Small coastal rivers are indeed important in the global budgets.
Modelling of riverine sediment fluxes

- purpose:
  - pollutant fluxes
  - temporal variability
  - anthropogenic impacts
  - natural controls

- scale:
  - large
  - small

- examples:
  - GoL
  - Med Sea
  - Tet, Rhone
Number of Q - TSS data pairs

<table>
<thead>
<tr>
<th>River</th>
<th>Data Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech</td>
<td>434</td>
</tr>
<tr>
<td>Tet</td>
<td>381</td>
</tr>
<tr>
<td>Agly</td>
<td>407</td>
</tr>
<tr>
<td>Aude</td>
<td>465</td>
</tr>
<tr>
<td>Orb</td>
<td>472</td>
</tr>
<tr>
<td>Herault</td>
<td>3490</td>
</tr>
<tr>
<td>Rhone</td>
<td>5021</td>
</tr>
</tbody>
</table>

6 Coastal rivers

Gulf of Lions

Rhone River
TSS - Q rating curves for FTSS calculations

Sadaoui et al., 2016
Rhone Mediteranean floods
Rhone - South alpine floods
Rhone - Northern floods
Saone
Upper Rhone
Isere
Durance
Ardeche
Ceze
St Ternay
St Valence

log TSS (mg/L)
log Q (mm/d)

Sadaoui et al., 2016
On average, the coastal rivers only contribute with about 5% to the total fluxes. For individual years, however, their contribution can strongly fluctuate (1% in 1983 and 27% in 2011).

Sadaoui et al., 2016
Spatial variability of river sediment yields in the Gulf of Lions drainage basin

FTSS (t km$^{-2}$ yr$^{-1}$)

6 coastal rivers
- Tech
- Tet
- Agly
- Aude
- Orb
- Herault
- Rhone
- Saone
- Upper Rhone
- Isere
- Durance
- Ardeche
- Ceze

Minimum: 19
Maximum: 151
FTSS(t km$^{-2}$ yr$^{-1}$) = 3.97 Tr + 0.04 Elev + 5.13 Rsa - 41.19

dr = 0.90
n = 12
(coastal rivers, Rhone tributaries)

ratio of sedimentary rocks / crystalline rocks > 750m

ratio of flood discharge / mean annual discharge
The Rhone River has (still) high sediment yields, mainly because of badland outcrops in the Durance and Isere tributaries.

Sediment yields in the coastal rivers are moderate. Basin size is not a control for sediment yields.
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  - Global
Coastal rivers

Rhone

Tet at Villelongue

Gulf of Lions

Arles

France

0 100 km
Sampling for particulate trace metals (PTM)
PTM - enrichment factors during flooding in the Tet River

Dumas et al., 2015
Specific fluxes (kg km\(^{-2}\) yr\(^{-1}\))

Tet

Rhone

Cr  Co  Ni  Cu  Zn  Cd\(^*\)  Pb

Dumas et al., 2015
Empirical models are only as good as the input data they use and do not always catch reality. They are nevertheless useful in the testing of large-scale hypotheses. Crossing of different scale models confirm the dominant control of hydroclimatic, morphological and lithological factors. Consideration of sediment rocks in elevated areas and the formation of badlands are probably a key for model improvements.
Cited references


