Ecosystem Services, part 3: Sediment Retention

The Science

- Underneath each InVEST model, there is a large literature and synthesized science
 - Here is a small excerpt related to sedimentation
- Too much content to cover here, but is in the extensive Users Guide
 - Instead, I will present a quick "stylized version" of what's being computed.



Figure 1. General catchment sediment budget. The relative size of the arrows changes depending on the environment. The InVEST model focuses on the overland sources and sinks, and does not include the others.

Annual Soil Loss

The amount of annual soil loss on pixel i, $usle_i$ (units: $tons \cdot ha^{-1}yr^{-1}$), is given by the Revised Universal Soil Loss Equation (RUSLE1 - Renard et al. 1997):

$$usle_i = R_i \cdot K_i \cdot LS_i \cdot C_i \cdot P_i, \tag{69}$$

where

- R_i is rainfall erosivity (units: $MJ \cdot mm(ha \cdot hr \cdot yr)^{-1})$,
- K_i is soil erodibility (units: $ton \cdot ha \cdot hr(MJ \cdot ha \cdot mm)^{-1}$),
- LS_i is a slope length-gradient factor (unitless)
- C_i is a cover-management factor (unitless)
- and P_i is a support practice factor (Renard et al., 1997). (cf. also in (Bhattarai and Dutta, 2006)). (unitless)

The LS_i factor is given from the method developed by Desmet and Govers (1996) for a two-dimensional surface:

$$LS_{i} = S_{i} \frac{(A_{i-in} + D^{2})^{m+1} - A_{i-in}^{m+1}}{D^{m+2} \cdot x_{i}^{m} \cdot (22.13)^{m}}$$
(70)

where

• S_i is the slope factor for grid cell *i* calculated as a function of slope. *s* is the percentage slope and θ is the slope in degrees (Renard et al. 1997):

 $S = egin{cases} 10.8 \cdot \sin(heta) + 0.03, & ext{where } igsimes 8 < 9\% \ 16.8 \cdot \sin(heta) - 0.50, & ext{where } igsimes 8 \ge 9\% \end{pmatrix}$

- A_{i-in} is the contributing area (m^2) at the inlet of a grid cell which is computed from the Multiple-Flow Direction method
- D is the grid cell linear dimension (m)
- x_i is the mean of a spect weighted by proportional outflow from grid cell *i* determined by a Multiple-Flow Direction algorithm. It is calculated by

Sedimentation on a very simple LULC map





Hydrological routing depends on the topography of the area

- DEM: Digital Elevation model
- Literally from the Space Shuttle!
 - Basically shoots lasers at the same spot from two different directions to get a very precise elevation measurement.



DEM of Gura

The Gura is a critically important river in Kenya



Flow direction

- Calculated from the DEM.
 - Color indicates which direction (in degrees) the water is flowing.



SDR calculation for one pixel of interest

- Red: Upslope area
- Yellow: downslope path
- Calculate this for ALL the pixels.



Running the InVEST SDR model

Hit the "home" button to go back to the model selection

In invest-workbench

- screen.
- Select the Sediment
 Delivery Ratio
 model

Annual Water Yield	Nutrient Delivery Ratio	Set up a model from a sample datastack file (.json) or from an InVEST model's logfile (.txt):	Open
Carbon Storage and Sequestration	RouteDEM		
Coastal Blue Carbon Preprocessor	Scenario Generator: Proximity Based		
Coastal Blue Carbon	Scenic Quality		
Coastal Vulnerability	Seasonal Water Yield		
Trop Pollination	Sediment Delivery Ratio		
rop Production: Percentile	Urban Cooling		
op Production: Regression	Urban Flood Risk Mitigation		
elineatelt	Urban Stormwater Retention		
orest Carbon Edge Effect	Visitation: Recreation and Tourism		
GLOBIO	Wave Energy Production		
Habitat Quality	Wind Energy Production		
Habitat Risk Assessment			

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 Start by setting the Workspace folder

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- Start by setting the Workspace folder
- Create a new folder in the SDR model called results.
- Select this folder as your Workspace

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• Input the first five inputs.

In invest-workbench

- You can probably guess which is which by the file name.
 - Refer to the User's Guide link if you can't.

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Erosivity

 Map of rainfall erosivity, reflecting the intensity and duration of rainfall in the area of interest.



Soil Erodibility

 Map of soil erodibility, the susceptibility of soil particles to detachment and transport by rainfall and runoff.





- Now enter the Watersheds input.
- We have two options.
 - "watershed_gura.shp"
 - "subwatershed_gura.shp"
- Notice that we have a new file type (.shp)
 - This is a Vector file, also called a Shapefile
 - Or sometimes Area of • Interest (AOI) or just a Polygon.

In invest-workbench

- You can also add this to QGIS if you'd like to look at it.
- For now, select "watershed gura.shp"

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- Next, input the following ٠ "model parameters"
- Each of these values has • important scientific context from Hydrology.
- For now, however, we are • going to set them according to the Default Values reported in the InVEST User's Guide

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Next, input the following ٠ "model parameters"

- Each of these values has • important scientific context from Hydrology.
- For now, however, we are ٠ going to set them according to the Default Values reported in the InVEST User's Guide
 - Access the Users • Guide with the info icon.
- One of the key reasons for ٠ InVEST's success is the thorough documentation it provides.

In invest-workbench		 Threshold Flow Accumula
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	Thre	• Maximum SDR Value (rati can have.
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	Bors	μm; Vigiak et al. 2012). This p studies. Its default value is 0.8
	Max	• Maximum L Value (numbe value of the slope length para
	Bors	Values of L that exceed this an
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Threshold Flow Accumulation (number, units: number of pixels, required): that must flow into a pixel before it is classified as a

the expression of hydrologic connectivity and the sedow path reaches the stream, sediment trapping stops assumed to reach the catchment outlet. It is important so modeled streams come as close to reality as possirces and Working with the DEM for more

- nber, units: **unitless**, *required*): Borselli k parameter. fault value: 2.
- number, units: unitless, required): Borselli ICo
- Default value: 0.5.
 - io, *required*): The maximum SDR value that a pixel

(76). This is a function of the soil texture. More specifiion of topsoil particles finer than coarse sand (1000 parameter can be used for calibration in advanced 8.

er, units: **unitless**, *required*): The maximum allowed meter (L) in the LS factor.

re thresholded to this value. Its default value is 122 but e place it anywhere between 122-333 see Desmet and l., 1997.

One key parameter: Flow accumulation

- Determines how much water must flow before we define it as a stream
- Here, red values show where little water has accumulated yet, but as it goes downhill, it eventually becomes a stream (blue)



• Click Run!

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- Click the Open Workspace button.
- There are many more results than for the carbon model. Each has it's own interpretation.
- Load sed_export.tif into QGIS.

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- Pretty ugly on its own.
- One challenge for interpretation is that most values are very close to zero but some spots are very high.
- Let's colorize the map to showcase this.
- Double-click on the sed_export.tif in the Layers window

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- I chose a thematic Brown color ramp.
- Set the mode to Quantile.
- This makes it so each color has the same number of pixels in its range.
- Optionally, increase the number of classes to get a more detailed colorbar.

- Much prettier!
- This map plots the Tons of Sediment exported from each pixel into the stream network.
- This may be exactly the number you are looking to report to the policy maker.
- However, it is still not the "Ecosystem Service" itself.



Avoided Erosion (tons)



- Here I have added a new layer, sed_retention.tif and colorized it.
- I chose a linear colorbar. This will highlight the places that are particularly bad.
- The policy advice becomes clear here. Do not degrade this natural land in particular!

- Avoided Erosion (top)
- Avoided export (into the stream, bottom)
- Similar, but imply different optimal management strategies:
 - Preserve steep, erodible slopes versus preserve riparian vegetation along the stream



Recap

- The Sediment Delivery Model calculates both erosion and stream export
- Shows some locations can be orders-of-magnitude more important to conservation outcomes
- Foreshadow:
 - Originally, most InVEST Sediment runs focused on export (and its impact on reservoir sedimentation).
 - Valued via e.g. avoided dredging values
 - We also calculate erosion's impact on crop yield
 - Degraded soil has lower yields

Appendix



Concepts VALUATION

- Very context-specific!
- Built-in replacement and avoided cost approaches for reservoir dredging or water treatment
- In InVEST: retention is calculated using a reference scenario of **bare soil**
 - Retention = Export_{bare_soil} Export_{current_land_use}

