Deep Dive into the InVEST SDR Model

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PROGREEN

natural capital PROJECT

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OUTLINING THE MODEL

Two main components:

i) Estimation of soil erosion via USLE equation
ii) The Sediment Delivery Ratio (SDR)

Sediment Export = Erosion x SDR

What factors could be determining erosion rates here?

OUTLINING THE MODEL

1. Estimation of soil erosion using the **Revised Universal Soil Loss Equation (USLE)**
   - Maps soil loss on each pixel based on:
     - Slope length and steepness (LS factor)
     - Rainfall erosivity (R factor)
     - Soil erodibility (K Factor)
     - Vegetation Cover (C factor)
     - Conservation practices (P factor)

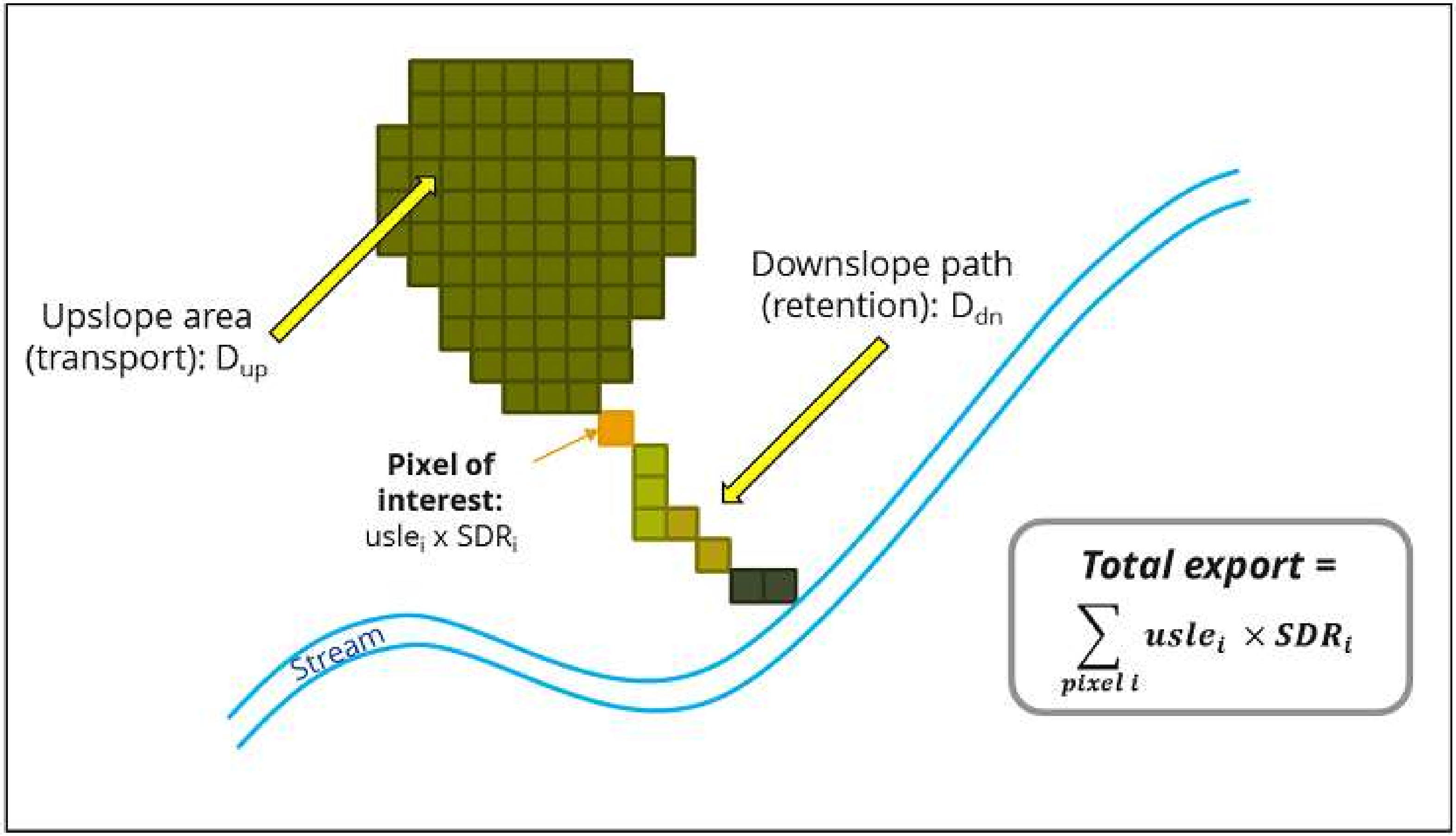
- **USLE = LS x R x K x C x P = annual erosion**

OUTLINING THE MODEL

2. Estimation of **the Sediment Delivery Ratio (SDR)**
   - For each pixel, calculates how much erosion actually reaches streams
   - Based on land cover and degree of hydrological connectivity

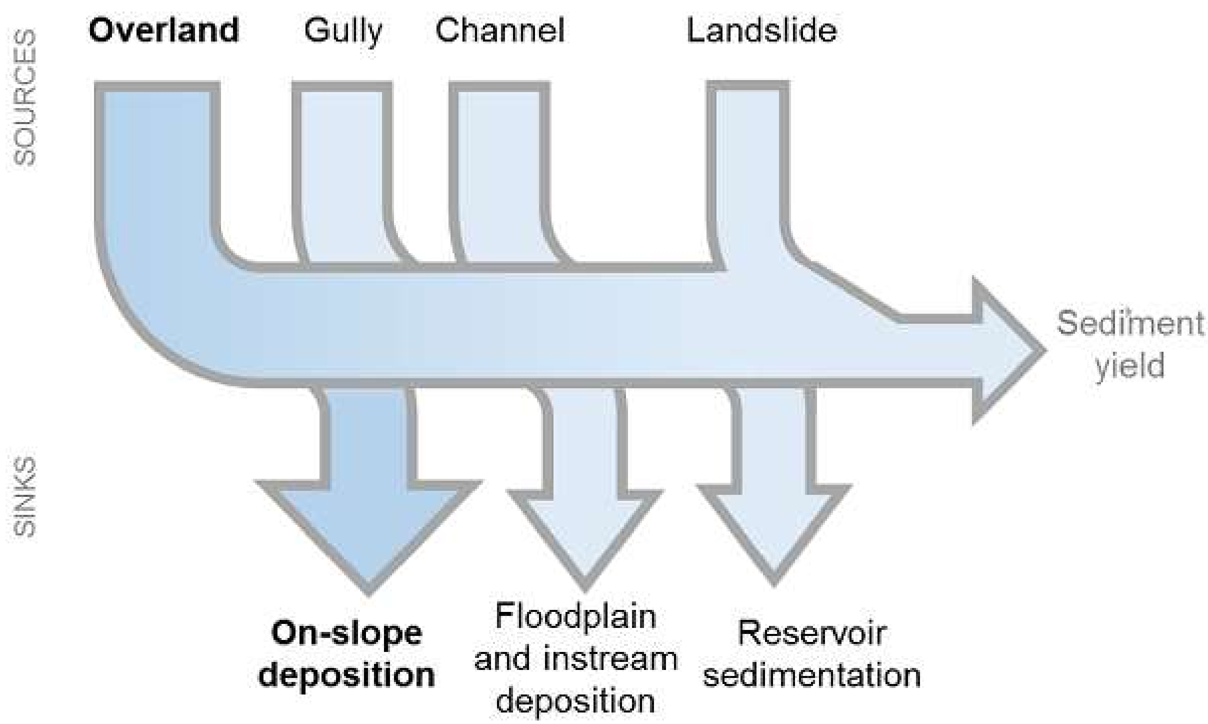
   - **Sediment export = USLE x SDR**

OUTLINING THE MODEL



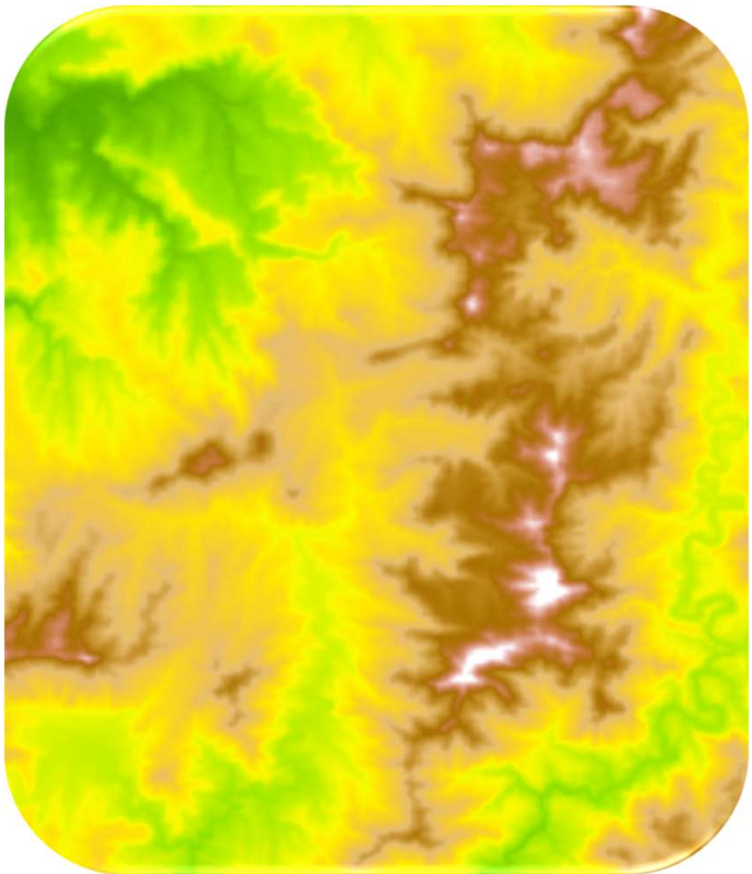
Sharp et al., 2020

LIMITATIONS



Sharp et al., 2020

- Considers only overland (sheet and rill) erosion
- Does not model instream deposition or sediment retention by reservoirs
- Uncertainty with parameter estimation e.g. C and P factors

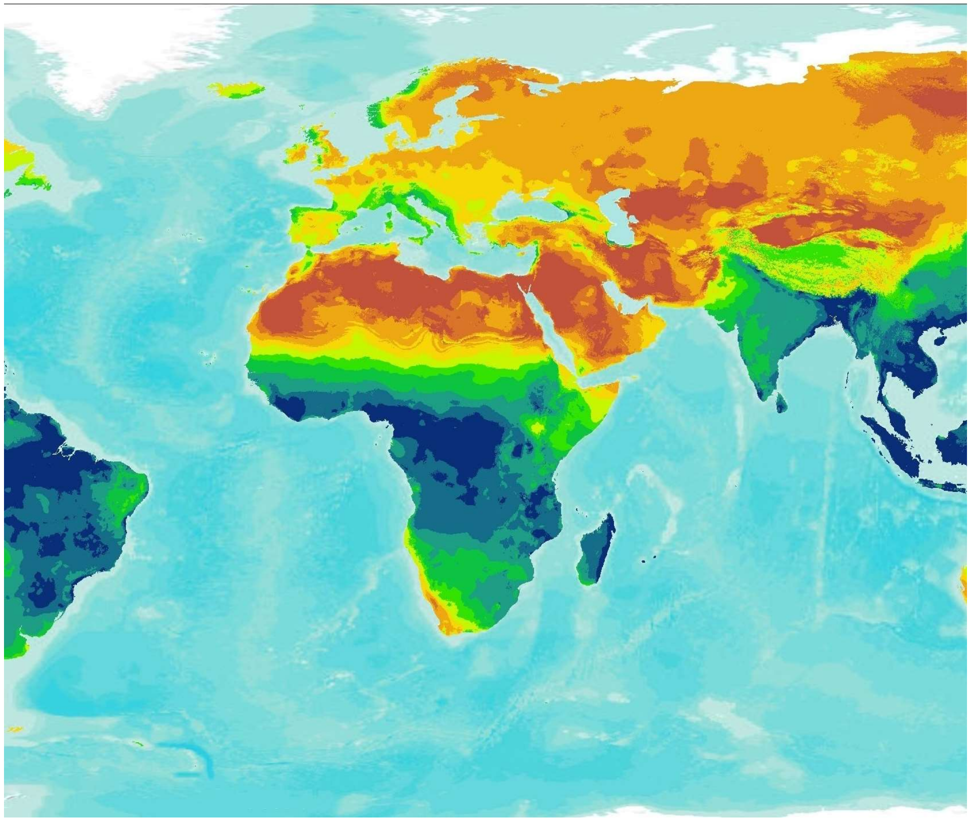


INPUT DATA

- Digital elevation model (DEM)
- Rainfall erosivity raster
- Soil Erodibility Raster
- Land use/land cover raster
- Watersheds shapefile
- Biophysical table to assign C and P factor values to different LULC classes

RAINFALL EROSIVITY (R FACTOR)

- Measured in MJ · mm/(h · ha · year)
- May be regional studies which provide equations to generate R from precipitation data
- Alternatively, global R factor map is available https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity



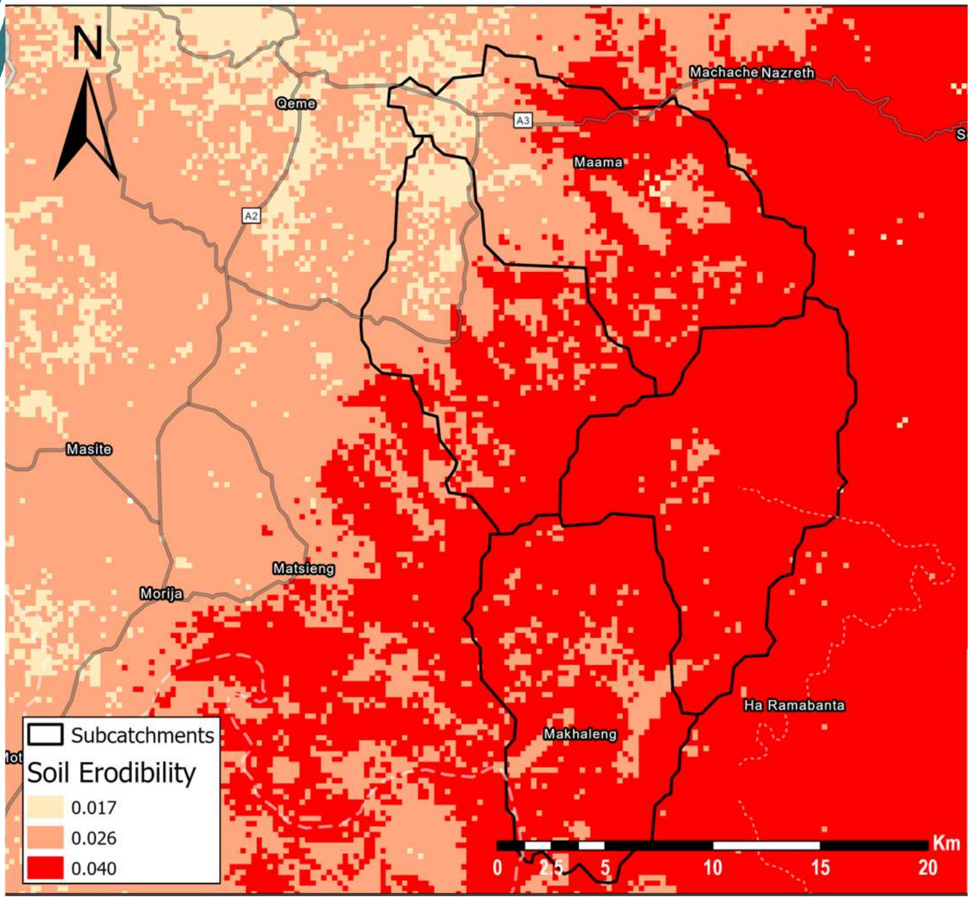
SOIL ERODIBILITY (K FACTOR)

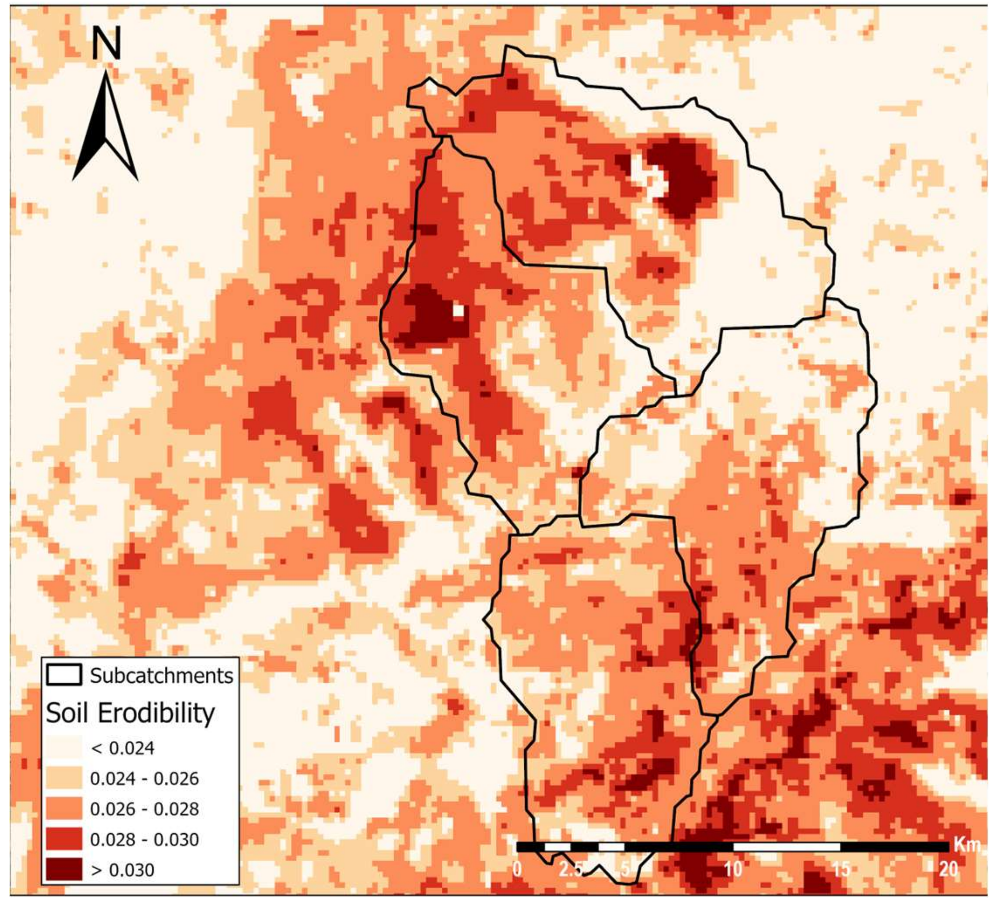
- Measured in t · ha · hr /(ha · MJ · mm)
- Primarily related to soil texture
- Can be calculated from various global soil parameters from the ISRIC soils database
- Can also be more quickly estimated from soil texture and organic matter content

$$K = \frac{2.1 \cdot 10^{-4}(12 - a)M^{1.14} + 3.25(b - 2) + 2.5(c - 3)}{759}$$

Texture class	Average OMC	OMC < 2%	OMC > 2%
Clay	0.0290	0.0316	0.0277
Clay loam	0.0395	0.0435	0.0369
Coarse sandy loam	0.0092	0.0092	0.0092
Fine sand	0.0105	0.0119	0.0079
Fine sandy loam	0.0237	0.0290	0.0224
Heavy clay	0.0224	0.0250	0.0198
Loam	0.0395	0.0448	0.0342
Loamy fine sand	0.0145	0.0198	0.0119
Loamy sand	0.0053	0.0066	0.0053

K FACTOR COMPARISON



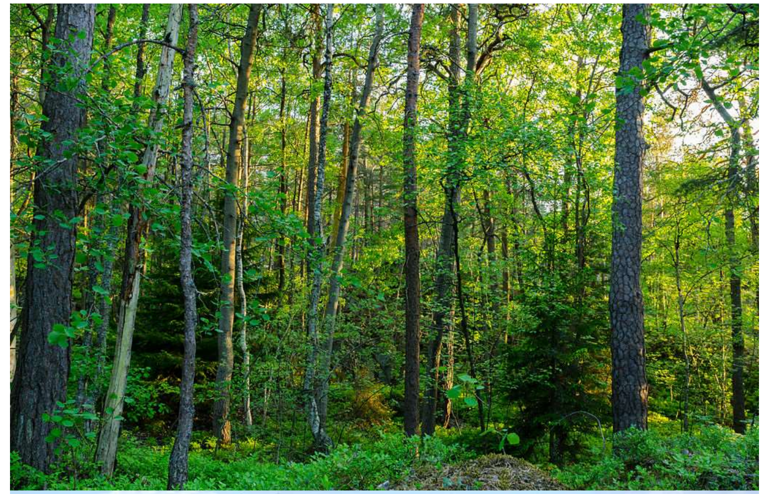
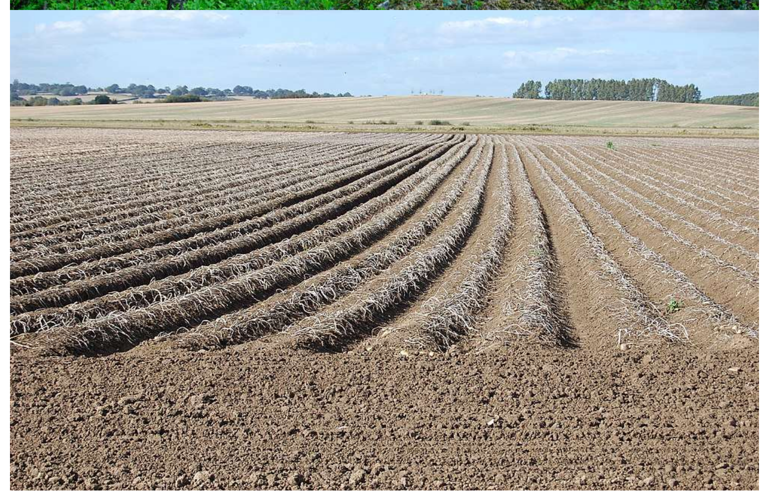


LAND COVER (P AND C FACTORS)

- Select best available land cover for the study area, or generate your own
- Used 2021 Lesotho Land cover Atlas data here
- Each LC class must have a corresponding C and P factor value in biophysical table
- Can alter LC raster and/or biophysical table to monitor the impact of LULC change or soil conservation actions

COVER (C FACTOR)

- Accounts for reduction in erosion due to vegetation cover: **Higher C Factor = higher erosion**
- Can obtain estimates from the literature for comparable land cover types

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COVER (C FACTOR): NON-ARABLE LANDS

Land cover type	Description	C-factor range	References
Closed forest (evergreen)	Tree canopy >70%, remains green all year. Canopy is never without green foliage.	0.0001–0.003	Borrelli et al. (2017); Panagos et al. (2015c); USDA (1977)
Closed forest (deciduous)	Tree canopy >70%, with an annual growing and dormant season.	0.0001–0.003	Borrelli et al. (2017); Panagos et al. (2015c); USDA (1977)
Open forest (evergreen)	Tree canopy 15–70%, remains green all year. Canopy is never without green foliage.	0.0001–0.003	Borrelli et al. (2017); Panagos et al. (2015c); USDA (1977)
Open forest (deciduous)	Tree canopy 15–70%, with an annual growing and dormant season.	0.0001–0.003	Borrelli et al. (2017); Panagos et al. (2015c); USDA (1977)
Shrublands	Woody perennial plants with persistent and woody stems less than 5 m tall.	0.01–0.15	Borrelli et al. (2017); de Vente et al. (2009); Bakker et al. (2008)
Herbaceous vegetation	Plants without permanent stems. Tree and shrub cover is less than 10%.	0.01–0.15	Bakker et al. (2008); Borselli et al. (2008); Panagos et al. (2015c)
Bare/sparse vegetation	Lands with exposed soil, sand, or rocks with vegetation cover never exceeding 10%.	0.10–0.50	Borselli et al. (2008); de Vente et al. (2009); Panagos et al. (2015c)
Urban and built-up	Land covered by buildings and other man-made structures such as roads.	0.0	de Vente et al. (2009); Pelacani et al. (2008)
Water bodies	Lakes, reservoirs, and rivers. Can be either fresh- or salt-water bodies.	0.0	de Vente et al. (2009); Pelacani et al. (2008)

Fenta et al., 2020

COVER (C FACTOR): ARABLE LANDS

Crop group		C-factor
Cereal grains	Maize/sorghum	0.38
	Rice	0.15
	Other cereals	0.20
Legumes	Various	0.32
Oilseed group	Cotton	0.50
	Other oilseeds	0.28
Trees/fruit trees	Coffee	0.20
	Sugarcane	0.15

Fenta et al., 2020

- C factor varies by crop
- Values are for conventional ploughing, without crop residues or other measures to increase soil cover
- C factor reduced for different management practices:
  - Tillage practices (conservation or no tillage vs conventional tillage)
  - Crop residue retention
  - Cover cropping

$C_{MANAGEMENT}$ FACTOR FOR ARABLE LAND

$$C_{management} = C_{tillage} \times C_{cover} \times C_{residues}$$

Assumptions:

- Con. tillage = 65% erosion reduction
- Cover crops = 20% erosion reduction
- Crop residues = 12% erosion reduction

Example: Area with 30% of maize under conservation tillage, 25% of fields have cover crops and retain crop residues

Calculations based on erosion reduction potential and proportional coverage of the practice:

- $C_{tillage}$ = (0.35 x 0.30) + (1 x 0.7) = 0.805
- C_{cover} = (0.8 x 0.25) + (1 – 0.25) = 0.950
- $C_{residues}$ = (0.88 x 0.25) + (1 – 0.25) = 0.970

- $C_{management}$ = 0.805 x 0.960 x 0.976 = **0.742**

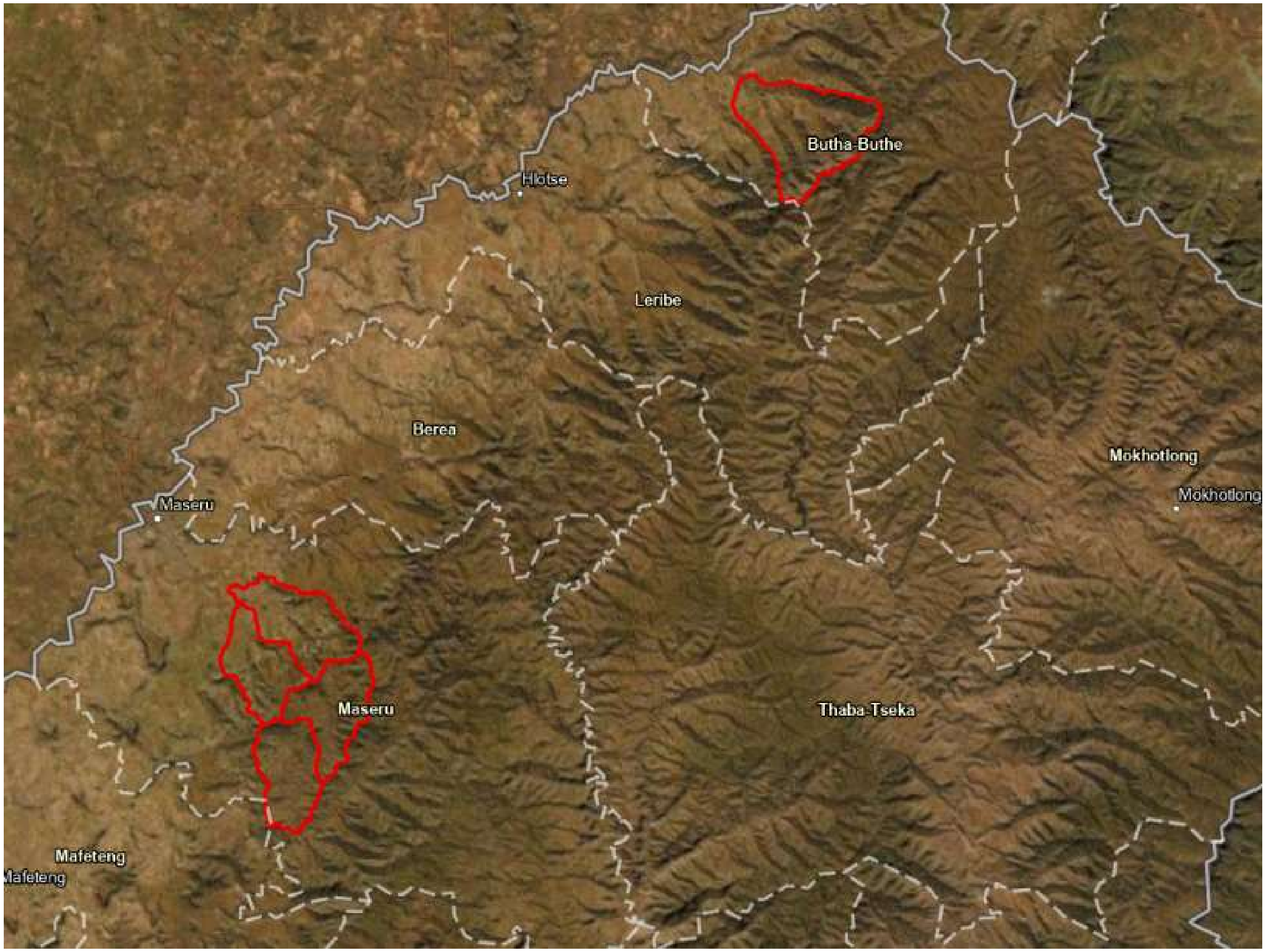
Revised C factor for maize = 0.38 x 0.742 = 0.282

CONSERVATION PRACTICES (P FACTOR)

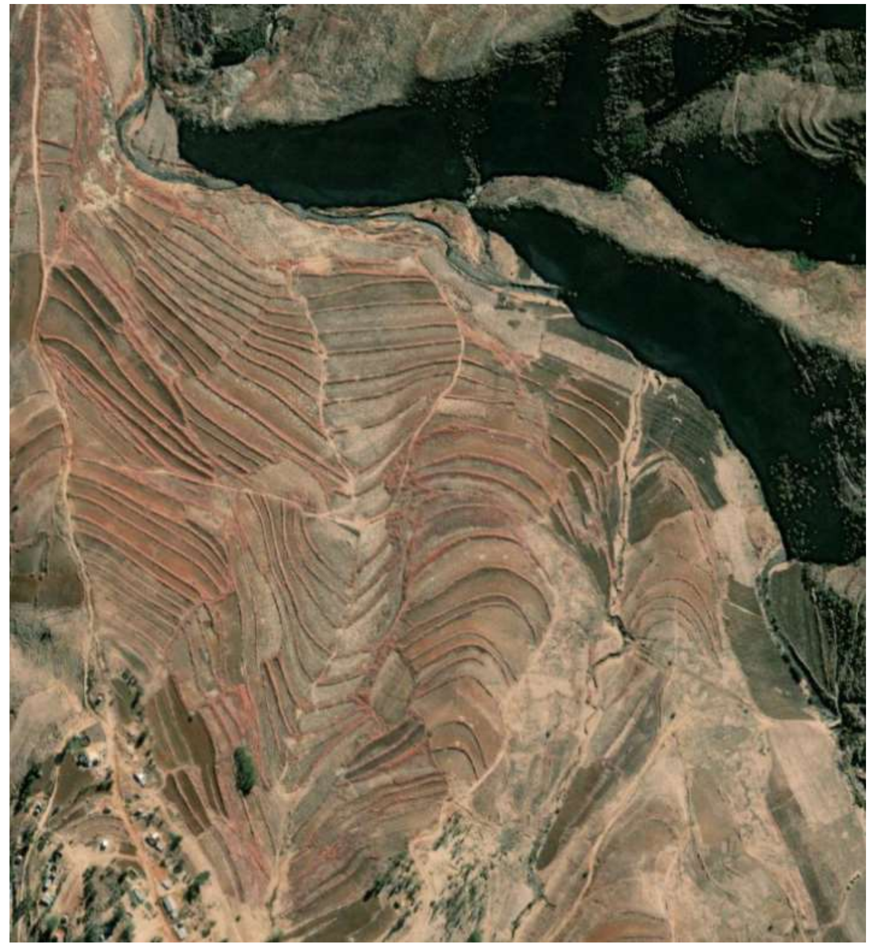
Support Practice	P factor
Up & down slope	1.0
Contour ploughing	0.7
Contour ploughing with grass strips	0.5
Contour bunds*	0.4
Bench terraces*	0.2

*P factor estimates are for well designed and maintained structures, often not the case in practice!

- Relevant to agricultural lands
- Accounts for the influence of contour ploughing, terracing and other measures, relative to straight up and down slope farming
- Set to 1 for natural land cover
- Often hard to estimate at scale


Butha-Buthe
Hlotse
Leribe
Berea
Mokhotlong
Mokhotlong
Maseru
Maseru
Thaba-Tseka
Mafeteng
Mafeteng

ESTIMATING P FACTOR



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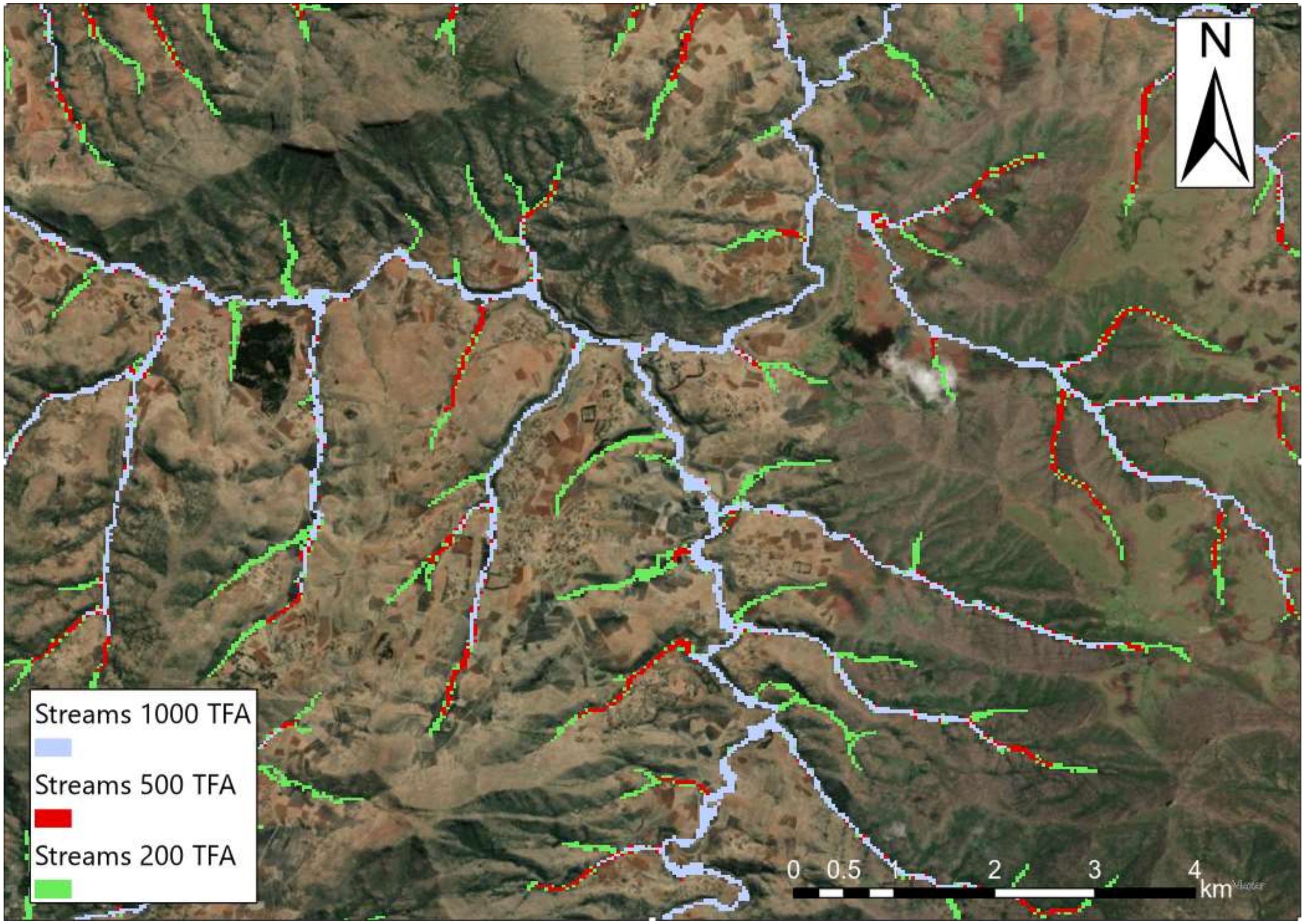
EXAMPLE BIOPHYSICAL TABLE

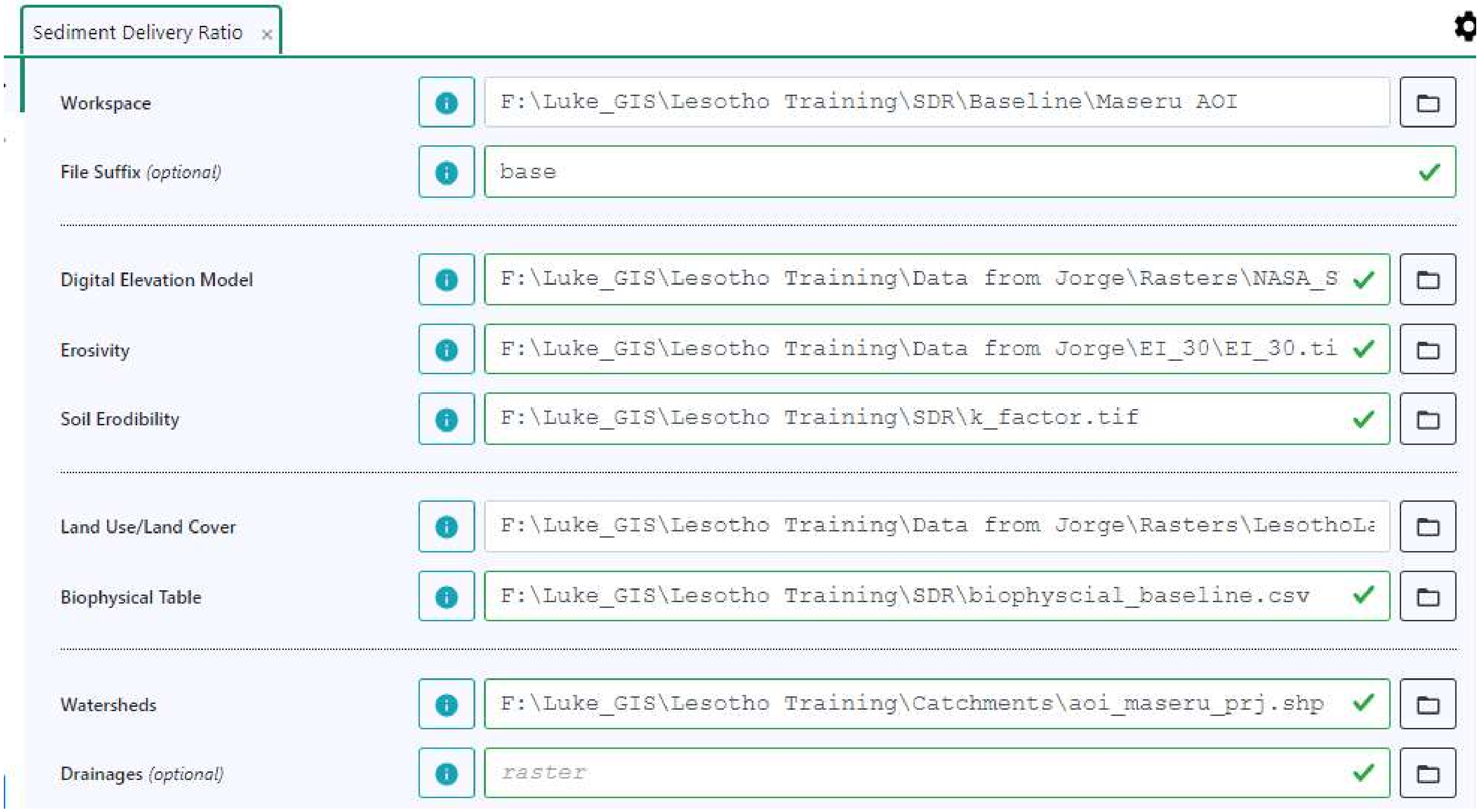
lucode	Descrip	usle_c	usle_p
1	Urban	0.05	1
2	Croplands	0.3	0.4
4	Forest/woodland	0.002	1
6	Water	0	1
7	Wetlands	0.01	1
9	Shrubland	0.01	1
10	Grassland	0.04	0.8
12	barren	0.4	1
14	Irrigated cropland	0.28	0.4
15	Gullies	1	1

OTHER INPUTS AND PARAMETER SETTINGS

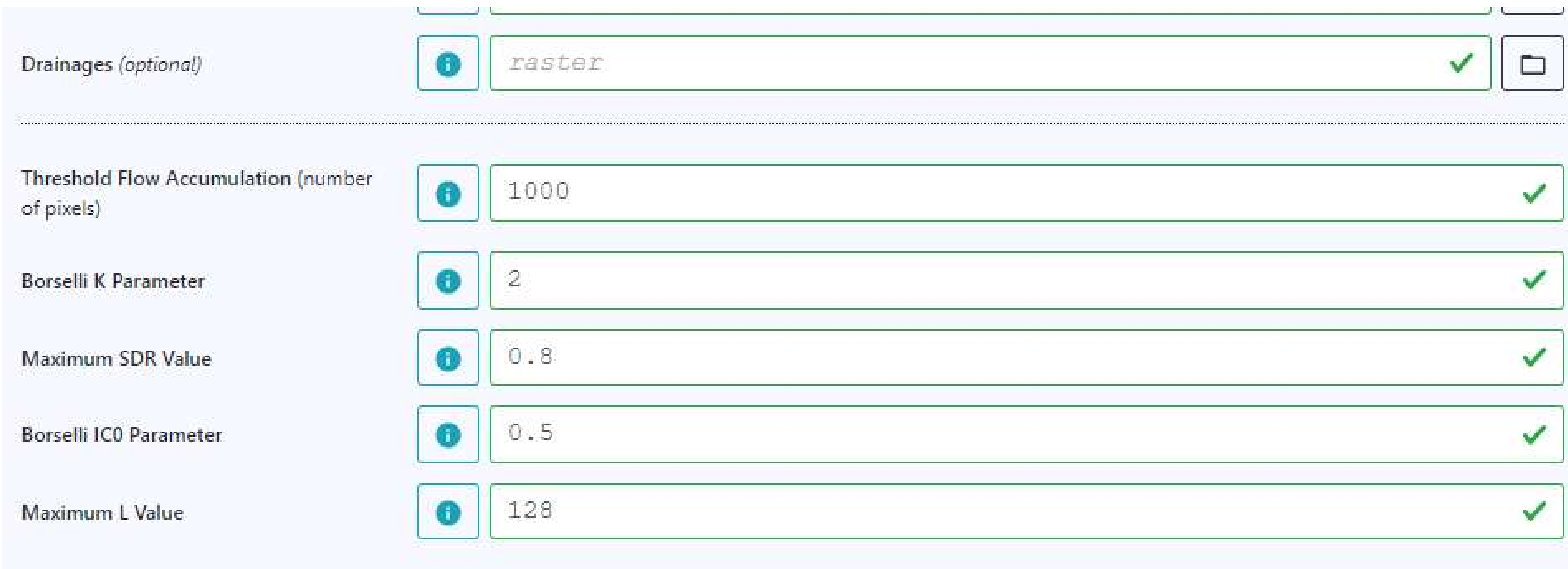
- **Threshold Flow Accumulation** - for stream delineation = the minimum number of upstream pixels which must drain into a given pixel for it to be considered a stream
- **Borselli K_b and IC_0 parameters** – Advanced parameters for calibration and sensitivity analysis
- **Maximum *SDR* value** – For calibration in advanced studies, related to fraction of fine particles in topsoil
- **Maximum *L* value** - limits the value of the slope length parameter in the LS factor calculation


Streams 1000 TFA
Streams 500 TFA
Streams 200 TFA
N
0
0.5
1
2
3
4
km

INVEST SDR USER INTERFACE



INVEST SDR USER INTERFACE



TEA BREAK

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KEY MODEL OUTPUTS

- Potential soil erosion (USLE)
- Sediment export to watercourses
- Sediment retention (relative to bare landscape) – Should be interpreted as a relative value
- Sediment deposition

CALIBRATION DATA

- Sediment export output can be compared with measured sediment yields
- Can use river sediment yield estimates or reservoir sedimentation studies
- River TSS or turbidity data can be converted to annual sediment load

Tegos et al. 2018

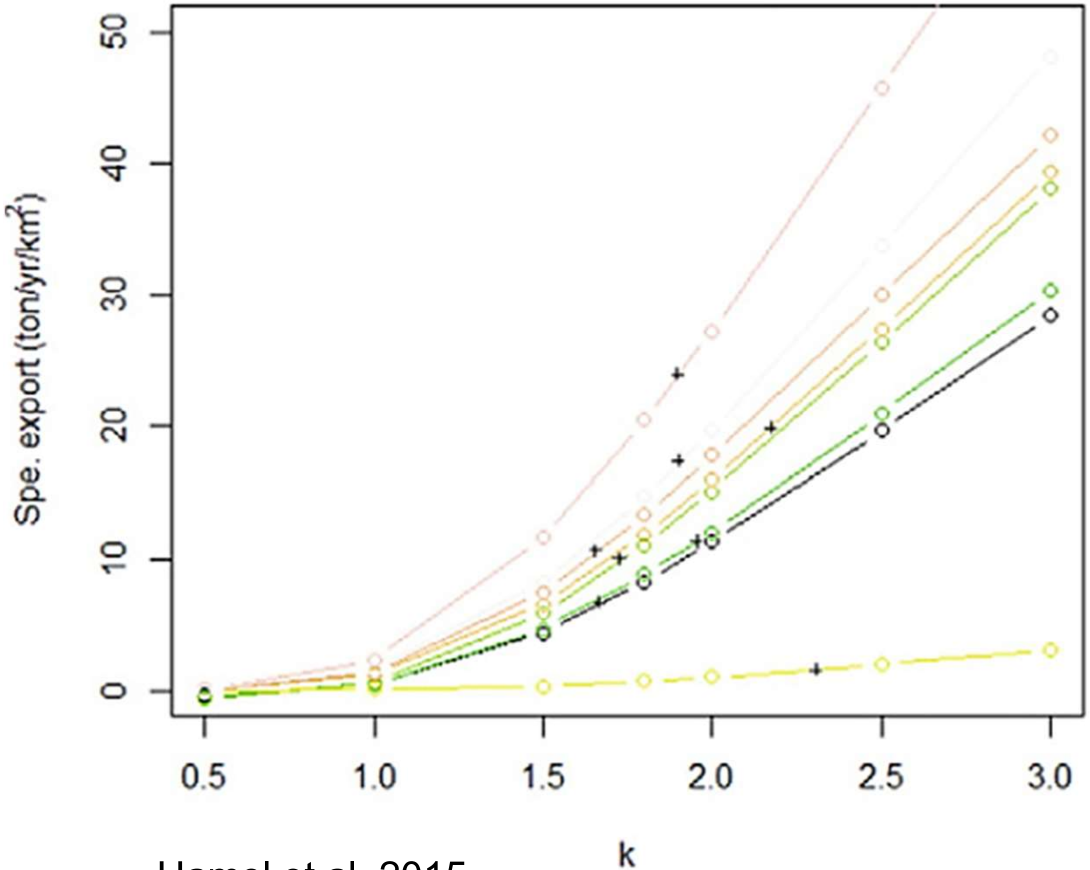
CALIBRATION: IMPORTANT ISSUES

- May require delineation of reservoir or gauging station catchment areas
- May need to convert sediment from t to m^3

- Be aware of sediment trapping by dams and omission of gully erosion and mass movements

CALIBRATION APPROACH

- Ideally would have data from multiple sub-catchments
- Calculate model bias for single or multiple catchments
- Alter C and P factor values of different land cover classes
- Incremental adjustment of the Borselli K parameter to minimise model bias



Hamel et al. 2015

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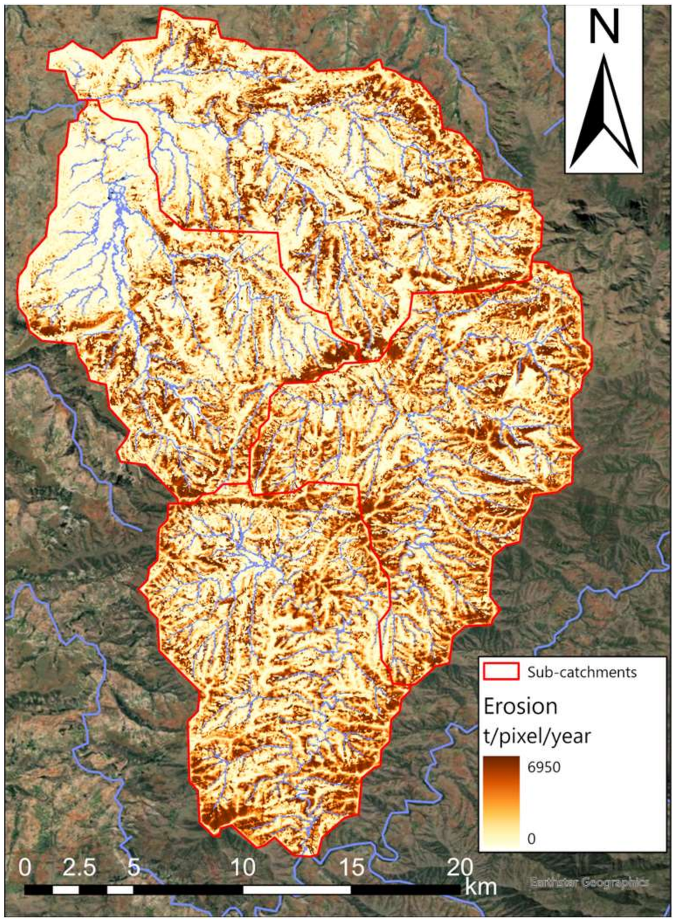
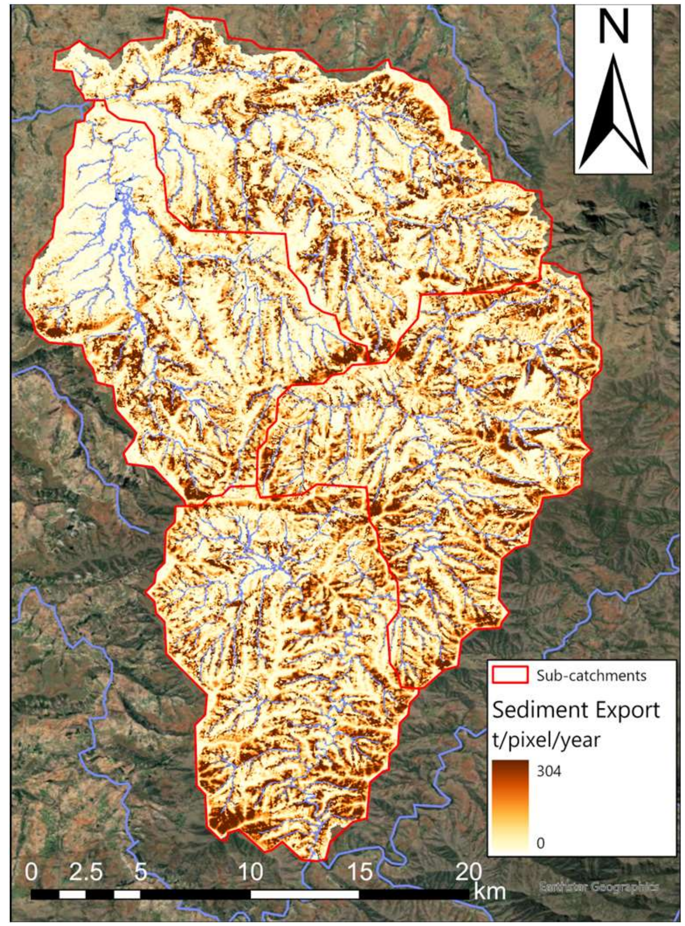
INTERPRETING RESULTS





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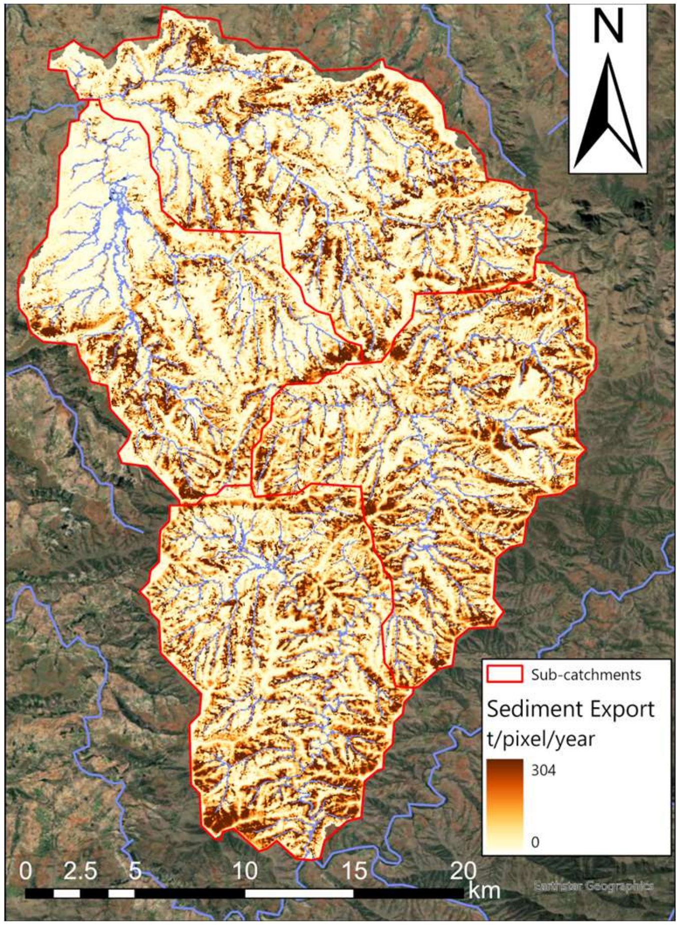

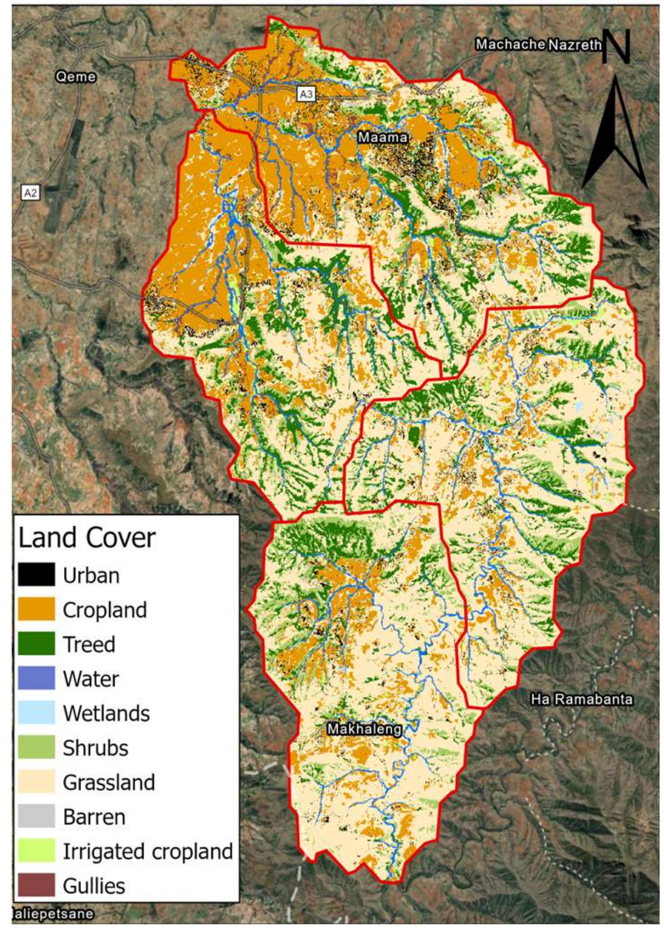

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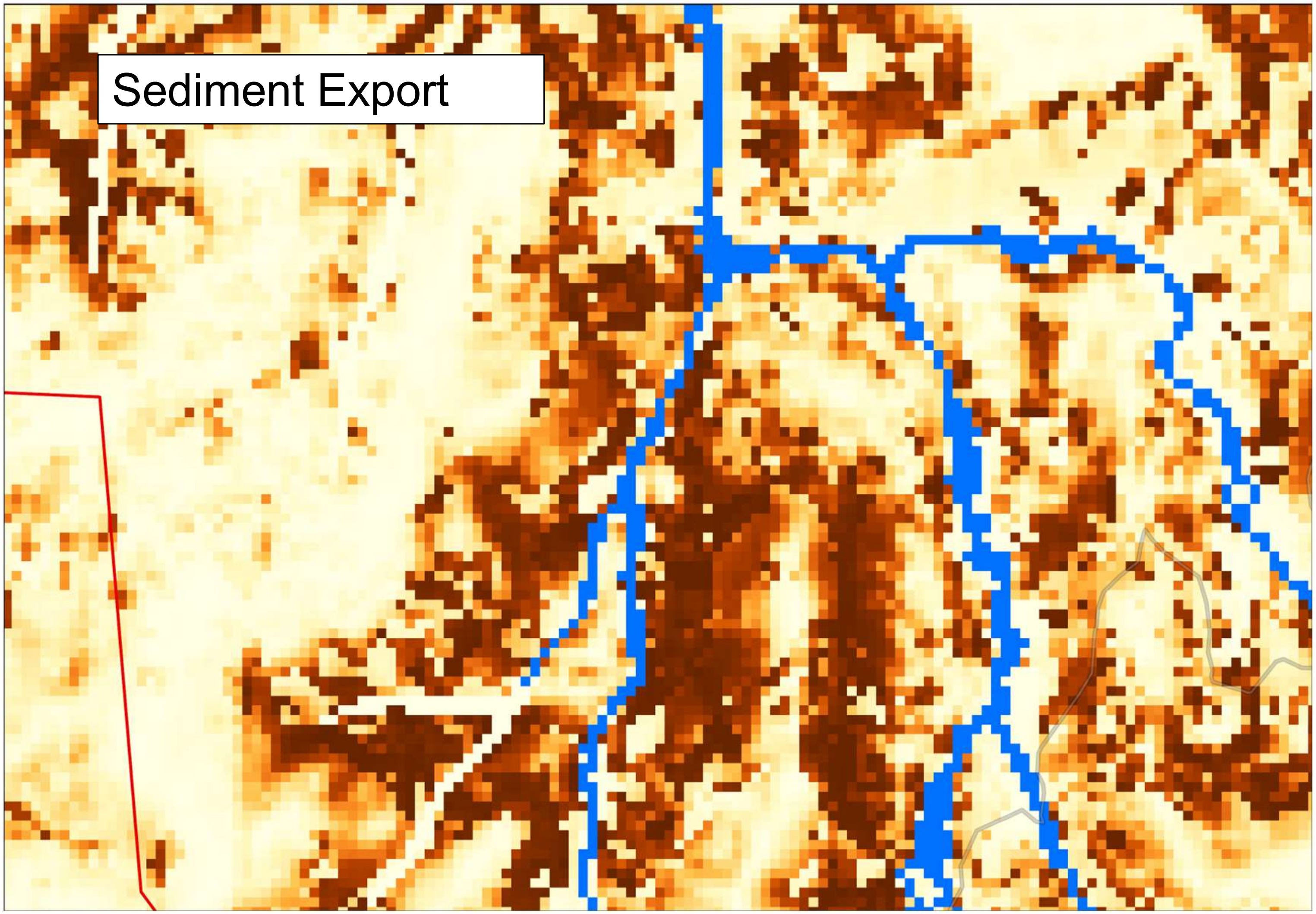
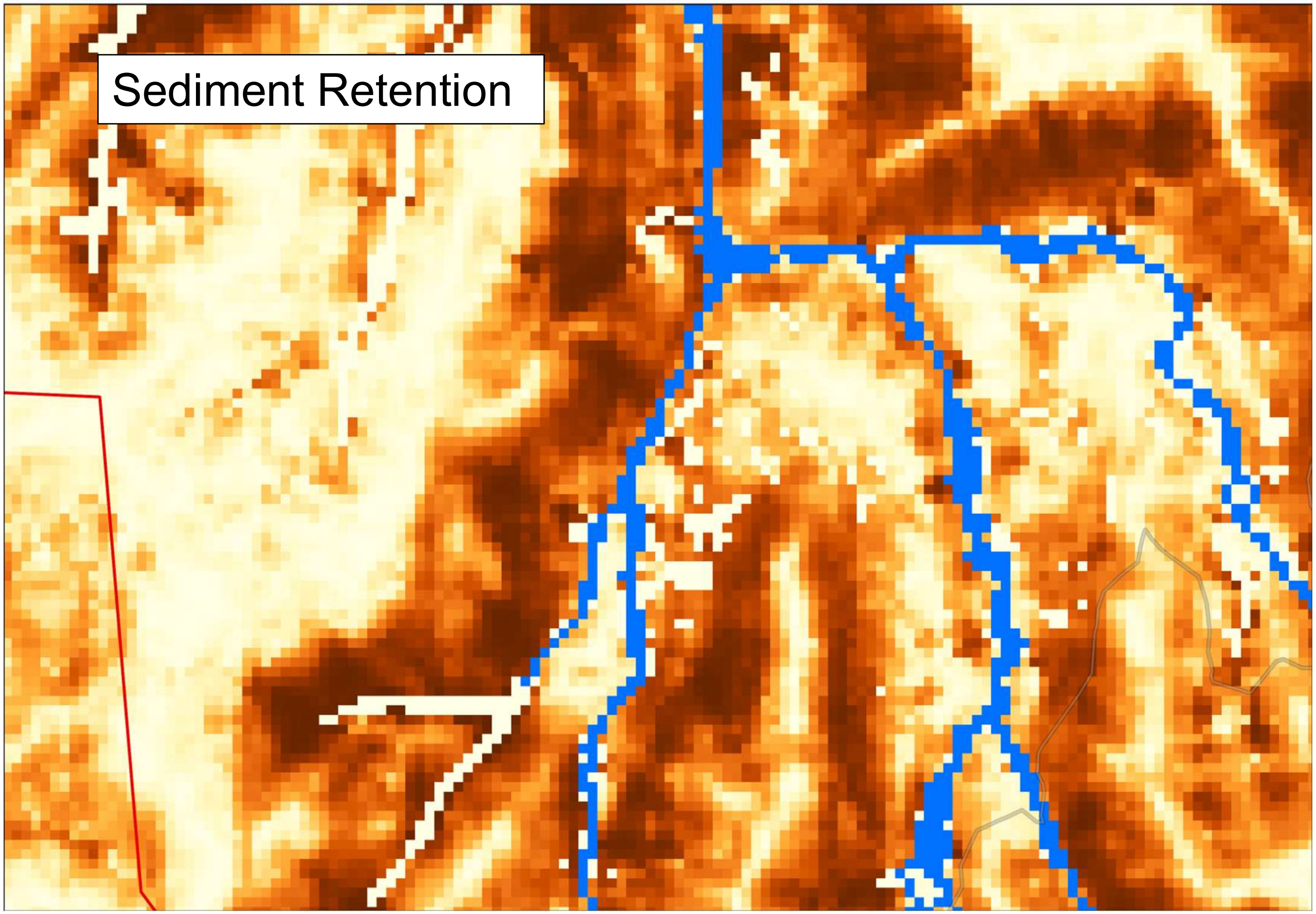
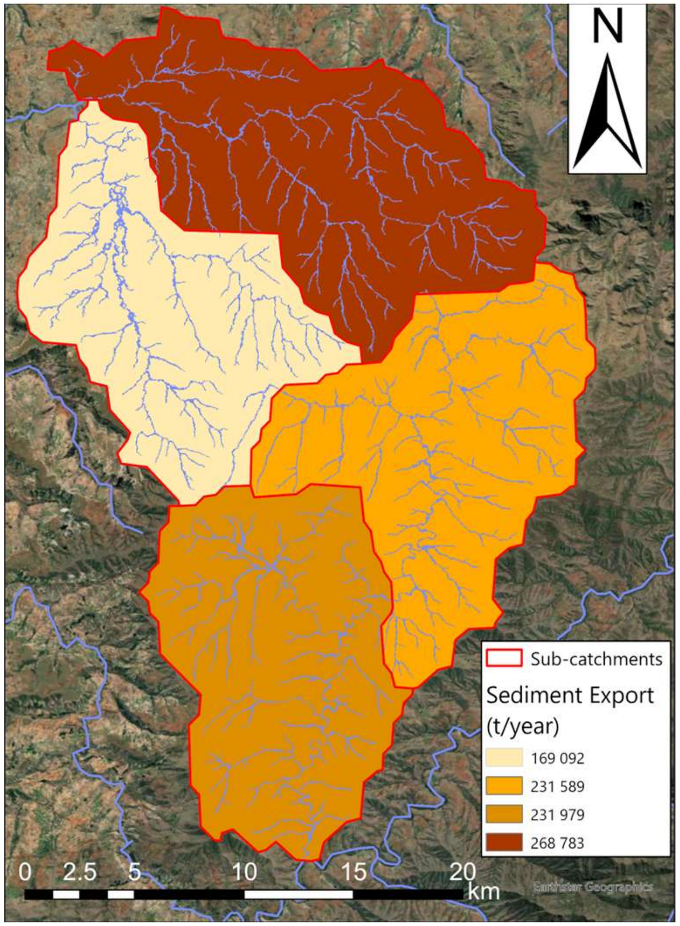

Sediment Export


Sediment Retention

INTERPRETING RESULTS



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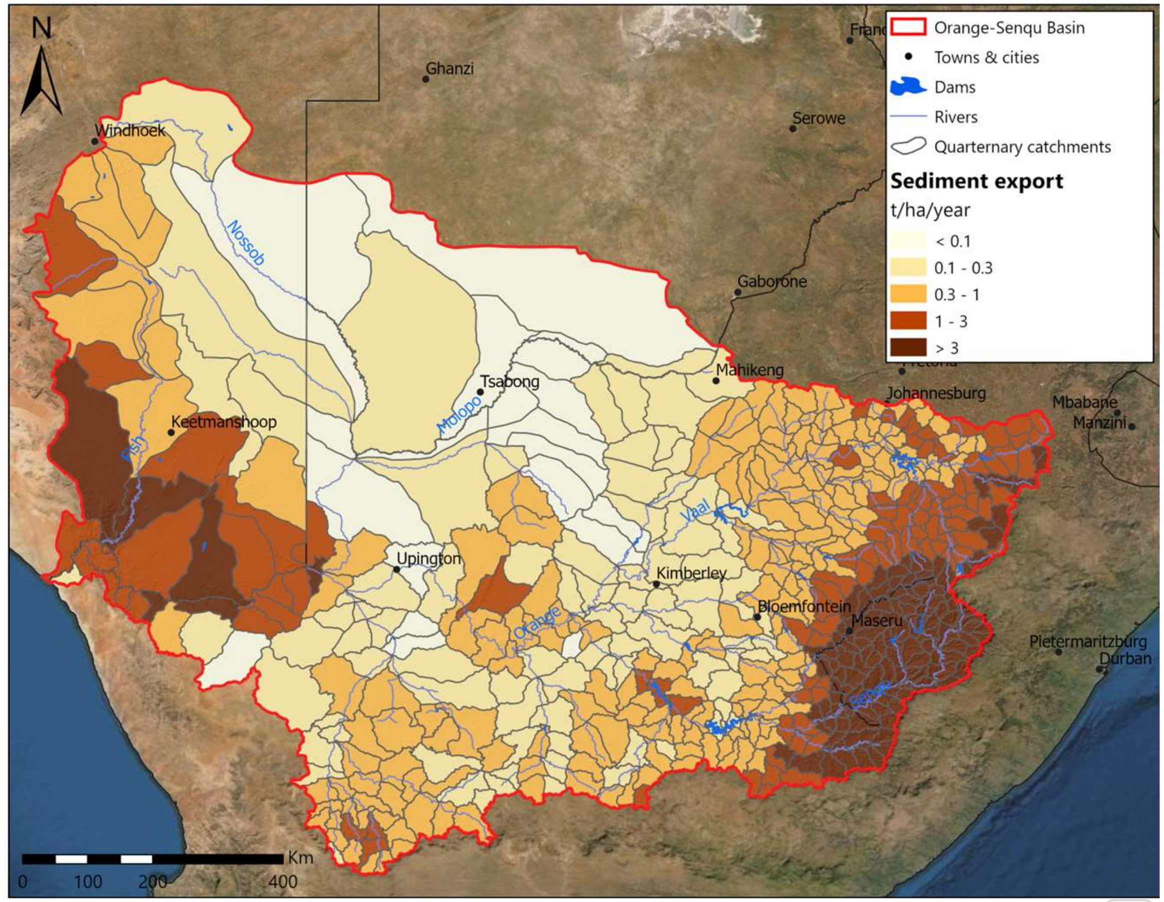
USING ZONAL STATISTICS IN GIS

Land Cover	Sediment export (t/year)	Sed. Export (t/ha/year)	Sed. Retention (t/ha/year)
Urban	8,229	6.3	148.8
Croplands	253,585	20.0	94.1
Irrigated cropland	12,023	19.5	99.8
Treed	17,836	3.0	738.7
Water	0	0.0	146.4
Wetlands	1,926	2.0	251.3
Shrubland	68,808	14.4	580.6
Grassland	383,942	15.1	359.1
Barren	43,267	96.6	181.1
Gullies	111,829	132.2	0.0
ALL	**901,445**	**17.0**	**340.9**

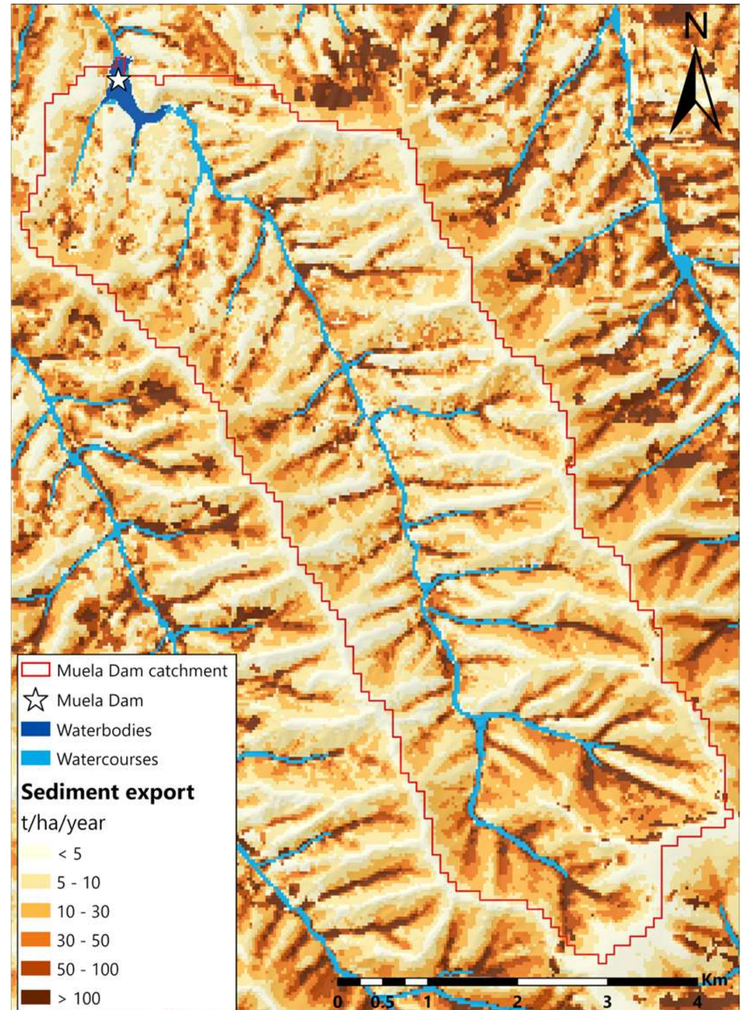
SIMPLE VALIDATION EXAMPLE: ORANGE-SENQU BASIN

- Modelled export comparable to historical sediment yield estimates at Orange River mouth
- Model estimated 142 Mm^3/year sediment export, compared to 120 Mm^3 **historical estimate**
- Historical estimate used to obtain sediment yield in absence of dams



SIMPLE VALIDATION EXAMPLE: MUELA DAM

- Annual reservoir sedimentation rates estimated
- 15 400 m^3/year (Khaba and Griffiths 2017), 30 000 m^3/year (LHDA, 2018)
- Delineate dam catchment area and compare sediment export estimate from InVEST
- Adjusted C and P factors to obtain modelled estimate of 31 400 m^3/year



SELECTING IMPROVED LAND MANAGEMENT INTERVENTIONS

Discussion Points

What interventions could be used to reduce erosion and sedimentation from farmland?

What interventions could improve grassland cover in degraded rangelands?

DESIGNING AND ASSESSING FUTURE MANAGEMENT SCENARIOS

Parameterising future management scenarios

- Changing land cover classes
- Adjust the C factor with restoration/degradation of natural habits or improved farming practices
- Adjust the P factor for arable lands
- Adjust R factor to reflect future rainfall change

Assessing the impact of alternative management scenarios

- Compare sediment export to baseline or BAU scenario
- Differences can be valued e.g. avoided reservoir sedimentation
- Costs and benefits can be used for cost-benefit analysis

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BUSINESS AS USUAL SCENARIO

- Assume, for example, gullies will expand
- Can add in a climate change assumption e.g. 10% increase in rainfall erosivity

- For a more advanced study, ideally would do a land cover change projection and/or evaluation and projection of land degradation trends

PARAMATERS FOR A SIMPLE FUTURE RESTORATION SCENARIO

Improved grass cover reduces C factor for grassland from 0.05 to 0.035

Assume 50% of farmers adopt conservation tillage:
$C_{tillage}$ factor = (0.5*0.35) + 0.5 = 0.675
C factor for cropland becomes 0.30 x 0.675 = **0.203**

Improved erosion control measures (e.g. stone lines, grass strips, no up/downslope ploughing) reduces P factor for cropland from 0.7 to 0.5

Assume climate change will increase rainfall erosivity (R factor) by 10%