Assessing the effect of different spatial resolutions in soil erosion modelling – Case study in a highland tropical watershed in southeast Mexico

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Introduction

In Latin America and the Caribbean, the increase in maize production experienced in recent years is mainly due to an increase in arable land. The expansion of the agricultural frontier represents one of the causes of soil degradation (e.g. deforestation, overgrazing), being the removal of natural vegetation the originating process. The area of study, the *Mixteca Alta* in southeast Mexico, is often termed an "ecological disaster" because of the soil erosion problem. The *Yanhuitlan* formation, a geological feature product of fine continental sediments has been identified as highly erodible. The highly heterogeneous land use (forest, arable land, eroded land, fallow) and topography in the study region brings the opportunity to explore the spatial distribution of soil erosion and the effect of UAV-derived different spatial resolutions on hydrologic and soil erosion modelling

Objectives

- To predict soil erosion via modelling (OpenLISEM) at the study units (forest, fallow, maize and eroded) and its upscaling to the watershed level
- To assess the suitability of OpenLISEM as a predictor of soil erosion under different land uses and topographies
- To assess the effect of different DSM / DEM spatial resolutions on hydrologic (runoff) and soil erosion (sediment discharge, soil loss) modelling

Materials and methods

Study unit level soil erosion measurement

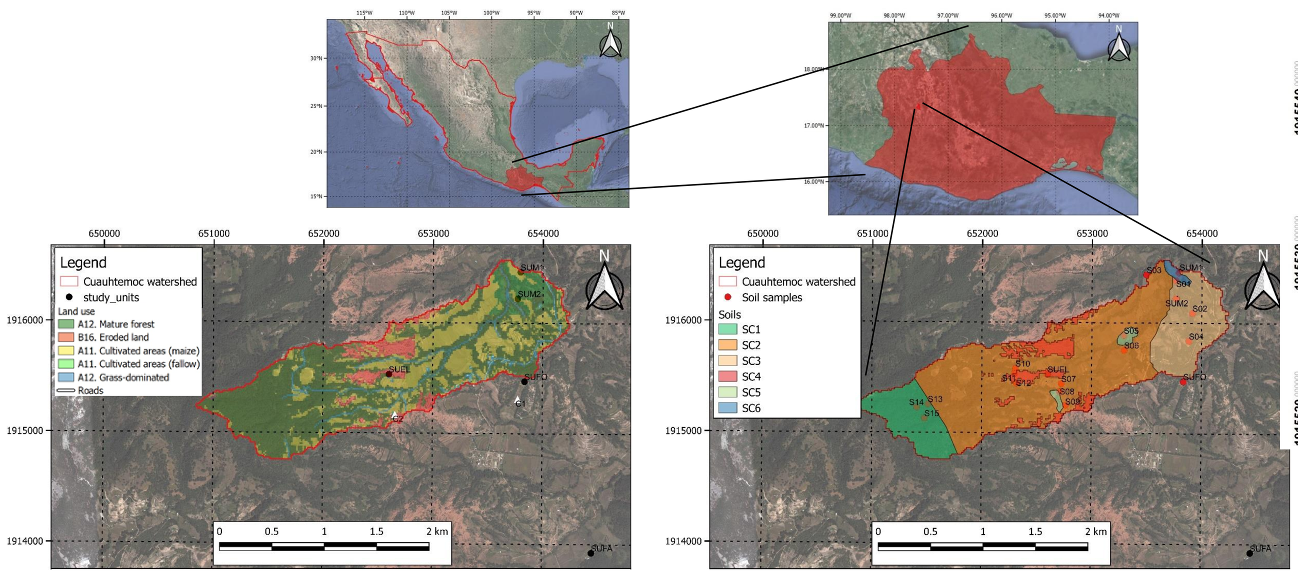


Figure 1. Map showing study site and plots

Study units (SU's)

- SUFO (forest): Wischmeier plot
- SUFA (fallow): Wischmeier plot
- SUM1 (maize): Monocropped micro-catch.
- SUM2 (maize): Monocropped micro-catch.
- SUEL (eroded): Yanhuitlan micro-catchment

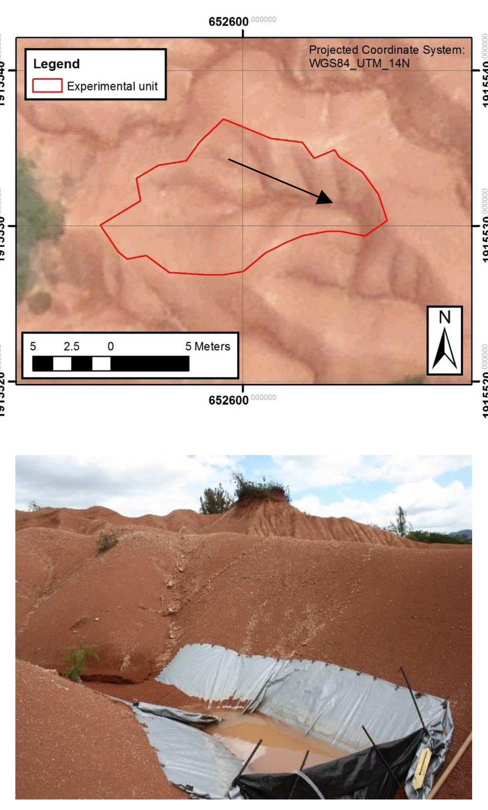


Figure 2. Layout of SUEL and collection site

Soil erosion modelling

OpenLISEM model

- Physically-based, spatially explicit
- Event-based runoff and erosion model
- 1-minute temporal resolution

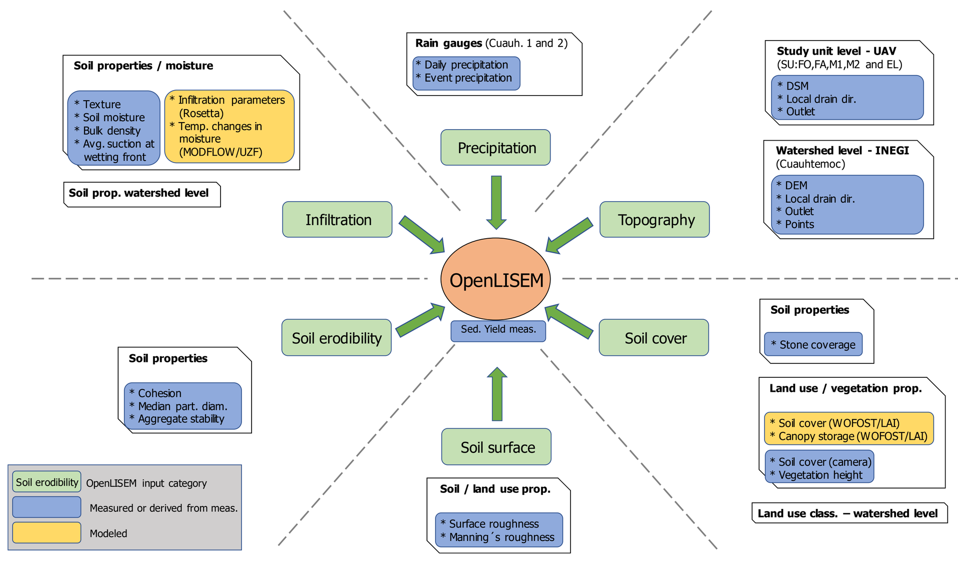


Figure 3. Flowchart of measured/derived data and their relation to the modelling process

Table 1. Modelling levels and parameters

Parameter	Study unit level	Watershed level
Land unit	SUFO, SUFA, SUM1, SUM2 & SUEL	Forest, maize, grass-dom., eroded, other.
Soil unit	SU dependent	SC1 to SC6
Timeframe	Mid May to mid August	Early May to end of Sept.
Resolution [m]	**UAV's DSM** 0.2 (baseline), 0.4, 1.0, 4.0, 8.0, and 15.0	**INEGI's DEM** 15.0

Results & conclusions

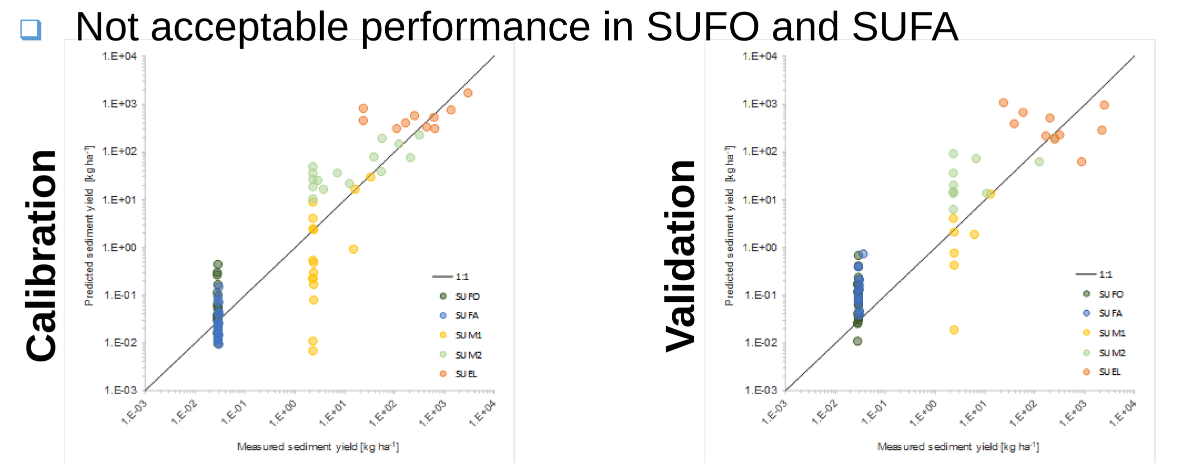
Erosion measurement, model cal. / val.

Measurement

- Negligible erosion in SUFO / SUFA (< 1 Mg ha^{-1})
- SY: SUEL=178.5, SUM2=14.8 and SUM1=0.8 [Mg ha^{-1} collection period^{-1}]

Model calibration / validation

- Cal. param's: cohesion, median part. diam., aggreg. stability
- Modif. of original values between 10^1 and 10^4 to achieve cal.
- Not acceptable performance in SUFO and SUFA



Calibration:

Study unit	CD (R sqr.)	EF	RMSE [Mg ha^{-1}]
SUM1 [n=28]	0.95	0.68	82
SUM2 [n=26]	1.51	0.61	131
SUEL [n=12]	4.83	0.54	101
All study units	2.32	0.72	228

Validation:

Study unit	CD (R sqr.)	EF	RMSE [Mg ha^{-1}]
SUM1 [n=14]	0.50	0.21	70
SUM2 [n=14]	1.75	0.61	120
SUEL [n=11]	4.87	-0.04	145
All study units	4.07	0.25	300

Figure 4. Calibration / validation results

Effect of different spatial resolutions (SU's)

Table 2. Diff. in topography (a) and in water balance components (b) in SUFO

a)

Study unit	Land use area [m^2]	Mean slope [m m^{-1}]	Longest distance to outlet [m]
SUFO			
0.2 m [original]	**81.8**	**0.538**	**25.6**
0.4 m	74.7	0.541	25.1
1.0 m	54.0	0.452	20.7
4.0 m	112.0	0.314	20.9
8.0 m	256.0	0.369	22.6
15.0 m[1]	225.0	0.305	0
15.0 m (INEGI)[1]	225.0	0.397	0

[1] One pixel

b)

Study unit	Inf./Prec. [mm mm^{-1}]	Roff/Prec. [mm mm^{-1}]
SUFO		
0.2 m [original]	**0.392**	**0.443**
0.4 m	0.367	0.535
1.0 m	0.313	0.607
4.0 m	0.283	0.642
8.0 m	0.307	0.619
15.0 m	0.298	0.631
15.0 m (INEGI)	0.305	0.622

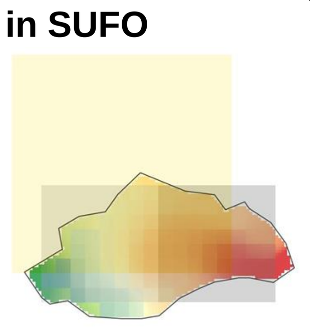


Figure 5. Example of resampled DSM set (0.2 [original], 1, 8, and 15 m) at SUEL

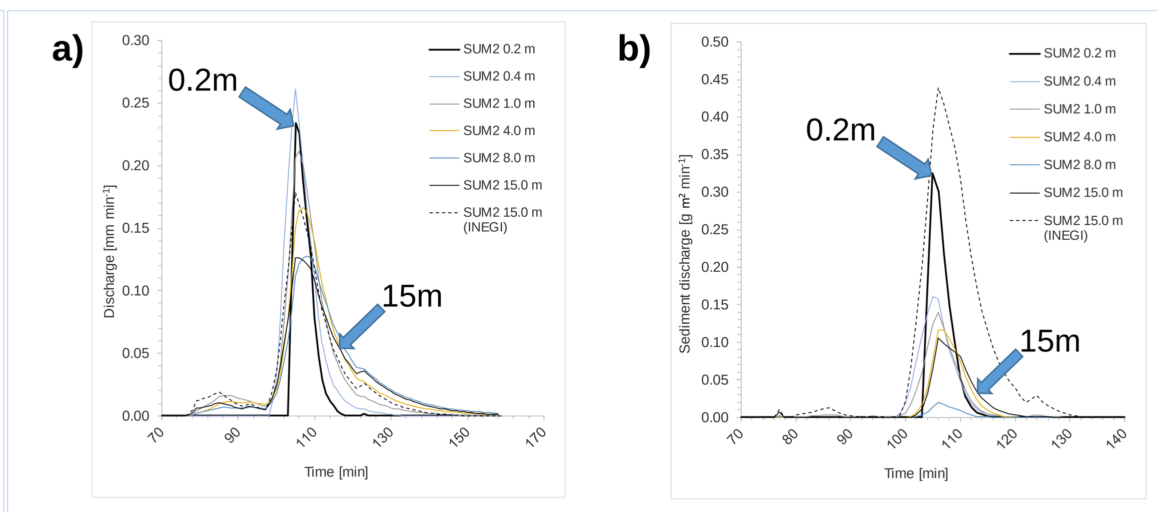


Figure 6. Discharge (a) and sediment discharge (b) at SUM2 on 06/27

Table 3. Sediment balance components at SUM2 on 06/29

Study units / resolutions	Det. [g m^2]	Dep. [g m^2]	Det. – |Dep.| [g m^2]	Sed$_{in-trans}$ [g m^2]	SY$_{outlet}$ [g m^2]
0629a (low)					
SUM2					
0.2 m	11.23	-8.95	2.29	0.92	1.37
0.4 m	11.00	-9.87	1.12	0	1.12
1.0 m	10.96	-10.02	0.95	0	0.95
4.0 m	10.99	-10.19	0.80	0	0.80
8.0 m	11.02	-10.91	0.11	0	0.11
15.0 m	11.02	-10.21	0.82	0	0.82
15.0 (INEGI)	11.00	-6.49	4.50		4.50

Conclusions of effect of different resolutions

- Consistent reduction of slope (Tab. 2a) and infiltration (Tab. 2b) as resolution decreases
- In general, largest peak discharge (pd, Fig. 6a) and sediment discharge (sd, Fig. 6b) corresponds to highest resolution (0.2 m) while lowest pd and sd corresponds to lowest resolution (15 m)
- In general, largest soil loss (Det. - |Dep.|, Tab. 3) corresponds to highest resolution while lowest soil loss corresponds to lowest resolution
- An increased slope (increased flow velocity) and reduced infiltration (increased runoff) amongst other factors is behind an increased soil loss and sediment yield in high resolutions

Erosion modelling at the watershed level

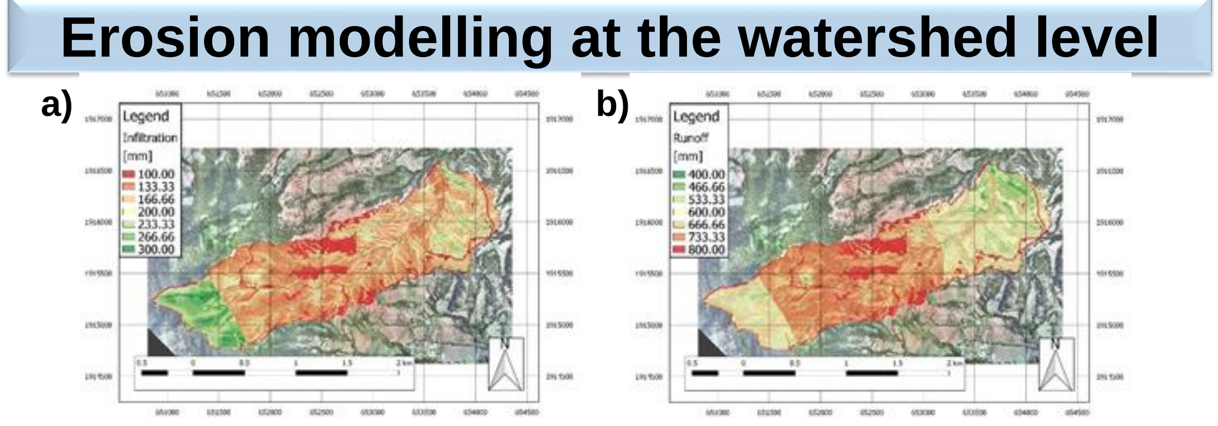


Figure 7. Collection period cumulative infiltration (a) and runoff (b)

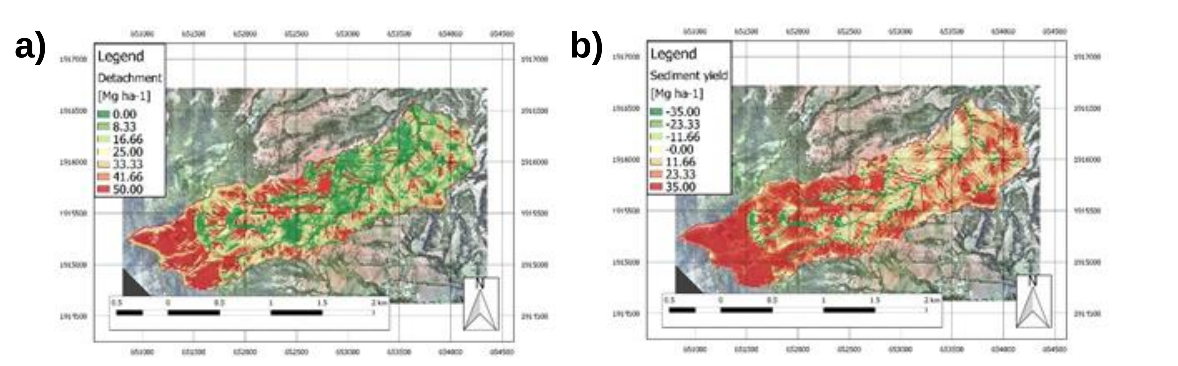


Figure 8. Collection period cumulative detach. (a) and sed. yield (b)

Table 4. Summary of predicted sediment balance during the coll. per.

Land use	Area [ha]	Det. [Mg ha^{-1}]	Det. [Mg]	Dep. [Mg ha^{-1}]	Dep. [Mg]	Det - |Dep| [Mg ha^{-1}]	Det - |Dep| [Mg]	S$_{in-trans.}$ [Mg ha^{-1}]	S$_{in-trans.}$ [Mg]	SY$_{outlet}$ [Mg]	SDR [-]
Overland											
Maize cult.	76.52 (0.31)	21.48	1 644.12	-10.56	-808.39	10.92	835.73	0.008	0.68		
Forest	138.33 (0.57)	55.63	7 695.93	-11.45	-1 583.77	44.18	6 112.17	0.08	11.17		
Grass dom.	12.30 (0.05)	23.57	290.13	-1.84	-22.70	21.72	267.42	0.01	0.14		
Eroded land	16.78 (0.07)	117.46	1 971.55	-0.89	-15.10	116.55	1 956.44	0.01	0.29		
Cuauhtemoc	**243.94 (1.00)**	**47.55**	**11 601.73**	**-9.96**	**-2 429.96**	**37.59**	**9 171.77**	**0.05**	**12.28**		
Channel											
Cuauhtemoc	**9.63**	**0.00**	**0.00**	**-945.61**	**-9 106.22**	**-945.61**	**-9 106.22**	**0.00**	**0.00**		
Total											
Cuauhtemoc	**243.94 (1.00)**		**11 601.73**		**-11 536.18**		**65.55**		**12.28**	**53.27**	**0.005**

Conclusions of modelling at the watershed level

- Non-acceptable model performance (over estimation) in forest and grass dominated land use
- Barely acceptable model performance in arable land (maize) and eroded land use
- OpenLISEM could not adequately predict erosion in typical low sed. yield conditions (i.e. highly cohesive soils, Tab. 4)