SOIL EROSION

IPROMO COURSE 2015

Food security in mountain areas EXtraordinary Potential

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Mountain Partnership
working together for mountain peoples and environments

NatRisk

UNIVERSITÀ
DEGLI STUDI
DI TORINO

Let’s talk about soil…..

- Watch

https://vimeo.com/53618201

Soil erosion – basic concepts

- *“Soil erosion is a natural process, occurring over geological time, and indeed it is a process that is essential for soil formation in the first place. “*

  This is related with landscape dynamics.
- “*With respect to soil degradation, most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased mostly by human activity.”*

(http://eusoils.jrc.ec.europa.eu/library/themes/erosion/)

Water erosion: detachment and displacement of fine soil particles due to water transport (runoff), and subsequent sedimentation. Consequence: soil redistribution.

Soil erosion – basic concepts

- Splash erosion: raindrop kinetic energy can cause topsoil aggregate breakdown

Related with: vegetation cover, tillage, manuring…

- Sheet erosion: water runoff removes a uniform layer of topsoil (difficult to see as water is not channeled)
- Rill erosion: channels (rills) a few cm deep (not visible any more after tillage)
- Gully erosion: deep channels (dm-m)
- Stream bank erosion

What is accelereted erosion?

- *"With a very slow rate of soil formation, any soil loss of more than 1 t ha^{-1}yr^{-1} can be considered as irreversible within a time span of 50-100 y. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t ha^{-1}in extreme events. The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing, forest fires and construction activities. "*

(http://eusoils.jrc.ec.europa.eu/library/themes/erosion/)

A new definition of soil erosion

Figure 1-1. Different types of soil erosion in the Urseren Valley: sheet erosion (A), landslide (B), rill erosion (D) and cattle trails (E).

Shallow hazards (topsoil)

Meusburger, 2010

Soil erosion – effects

- Topsoil loss
- Fertility loss
- Sediment accumulation
- Degradation of soil quality (chemical, physical, biodiversity….)
- Impact on soil functions (production, protection, etc, fertility..)
- …..= $ loss

Soil erosion effects - details

On-site	Off-site
Organic matter loss	Floods
Degradation of soil structure	Water pollution
Reduced infiltration	Sediment accumulation in rivers and on land
Reduced recharge of the watertable	Impacts on fishery resources and river/lake habitats
Nutrients loss	Eutrophication
Plant uprooting	Reduction of land value
Productivity loss	Land abandonment and effects on food security
Drought vulnerability	

Example of hidden costs: additional fertilizers need to compensate the loss of fertility…

Soil erosion costs (on-site + off-site)

- US: 30-40 billion $/y (Uri & Lewis, 1998; Pimentel et al., 1993)
- Indonesia (Java): US$ 400 million/y (Magrath & Arens, 1989)
- UK: £ 90 million/y (Env. Agency, 2002).

- Data from Morgan, 2010

Soil erosion facts

- Pimentel (1993) Lal (1994) Speth (1994) stated that at present ~80% of the world's agricultural land suffers moderate to severe erosion, 10% slight erosion. Worldwide, erosion on cropland averages about 30 t $ha^{-1}yr^{-1}$ and ranges from 0.5 to 400 t $ha^{-1}yr^{-1}$ (Pimentel et al., 1995).
- Consequence: abandonment of large surfaces of arable land


Erosione catastrofica dopo livellamento e scasso

Da Paolo Bazzoffi, ISSDS-2002

Soil erosion and CC

- Recent projections of climate scenarios (Schroter et al., 2005) indicated that in Europe, mountains will be the most vulnerable areas to erosion.
- IPCC, 2007: increase of intense storms and flash-floods is expected, with potential impacts on runoff, sediment yield, and natural hazard.
- Lal (1995) estimated that global soil erosion releases 1.14 Pg C annually to the atmosphere, of which some 15 Tg C is derived from the USA. Erosion contributes significantly to CC and CO_2 release into atmosphere enhances the greenhouse effect.

Soil erosion and CC: effects

- Changes in extent, frequency and magnitude

of soil erosion in a number of ways (Pruski and Nearing, 2002; Mullan, 2013).

- Changes in rainfall patterns
- Changes in rainfall erosivity (erosion capacity of rain)
- Land use and land cover changes (may determine increased or decreased erosion depending on soil cover and management)

Soil erosion mitigation

Morgan, 2005: *“Erosion control is a necessity in almost every country of the world under virtually every type of land use. Further, eroded soils may loose 75–80 per cent of their carbon content, with consequent emission of carbon to the atmosphere. Erosion control has the potential to sequester carbon as well as restoring degraded soils and improving water quality.”*

Erosion facts from Europe

- Reduced number of people employed in agriculture
- Land marginalization
- Need for mechanization
- Terrace abandonment in marginal areas
- Large-scale earth moving and land levelling, which makes the soil more erodible. Almost everywhere that land consolidation programmes have been carried out, rates of soil erosion have increased (Morgan, 2005)

1)Terraces in Southern Europe

- *Terraces: distinctive element in the European landscape*
- *Historical and cultural value*
- *Challenge for land conservation, agricultural quality, natural hazard prevention*
- *Overview on terraces distribution*
- *Terraces in Italian NW – Alps (soil and terrace properties)*
- *Best practices for terraces conservation*
- *www.alpter.net*

Two examples

1. Terraces in Southern Europe

2. Land reshaping in NW Italian Alps

Fig. 3 Relevant literature on terraced soils in Southern Europe. The map represents the study areas of the papers reported in reviewed literature , i.e. papers with a deeper focus on soils.

S. Stanchi , M. Freppaz , A. Agnelli , T. Reinsch , E. Zanini

Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps): A review

Quaternary International, Volume 265, 2012, 90 - 100

http://dx.doi.org/10.1016/j.quaint.2011.09.015

Fig. 4 The terraced landscape of Pont-Saint-Martin (Valle d’Aosta, Italy) in the XIX Century (G. Ladner, 1847, courtesy Mrs. Ardissone). Pergola vineyards are largely represented with extension comparable to present time

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Fig. 1 Terraced pergola vineyards in Pont-Saint-Martin (Valle d'Aosta, Italy) at present time. A large extension of well maintained pergola vineyards is visible on very steep slopes, often more than 100%, where mechanization is quite impossible.

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Fig. 2 Terraced slopes in Valle d'Aosta. Structural typologies and details (Photos M. Freppaz). a) wall foundation; b) connection between terraces (suspended stairs); c) example of restored wall; d) terraced slope – vineyard; e) terraced slope – chestnut wood

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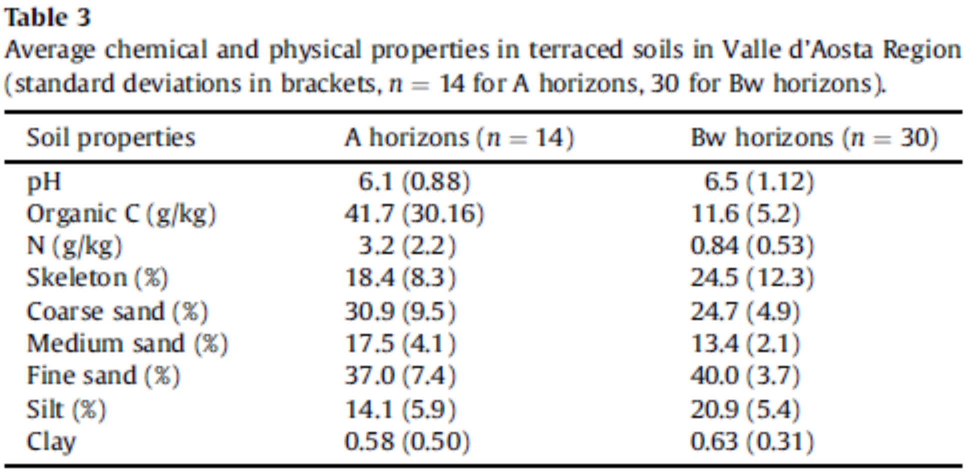


Table 3
Average chemical and physical properties in terraced soils in Valle d'Aosta Region (standard deviations in brackets, $n = 14$ for A horizons, 30 for Bw horizons).

Soil properties	A horizons ($n = 14$)	Bw horizons ($n = 30$)
pH	6.1 (0.88)	6.5 (1.12)
Organic C (g/kg)	41.7 (30.16)	11.6 (5.2)
N (g/kg)	3.2 (2.2)	0.84 (0.53)
Skeleton (%)	18.4 (8.3)	24.5 (12.3)
Coarse sand (%)	30.9 (9.5)	24.7 (4.9)
Medium sand (%)	17.5 (4.1)	13.4 (2.1)
Fine sand (%)	37.0 (7.4)	40.0 (3.7)
Silt (%)	14.1 (5.9)	20.9 (5.4)
Clay	0.58 (0.50)	0.63 (0.31)

2)Land reshaping: a case-study

- Intrinsic limitations of mountain agriculture (climate, topography, soils..)
- Land reshaping operations and intense soil rebuilding are carried out to improve accessibility and mechanization
- The effects of reshaping on soils are immediate, but may vary in the medium or long-time span
- Soil physical indices (aggregate stability, Atterberg limits) can be helpful in soil quality assessment
- Some examples of soil recovery after land reshaping are presented

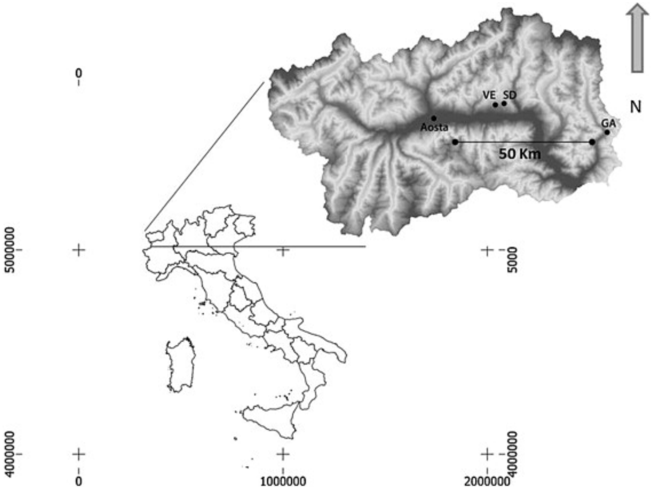


Fig. 4
Cantiere di
Septumian
(Chambave). In
basso a destra
sono visibili
le aree già
inerbite, mentre
i lavori stanno
proseguendo
negli altri settori.

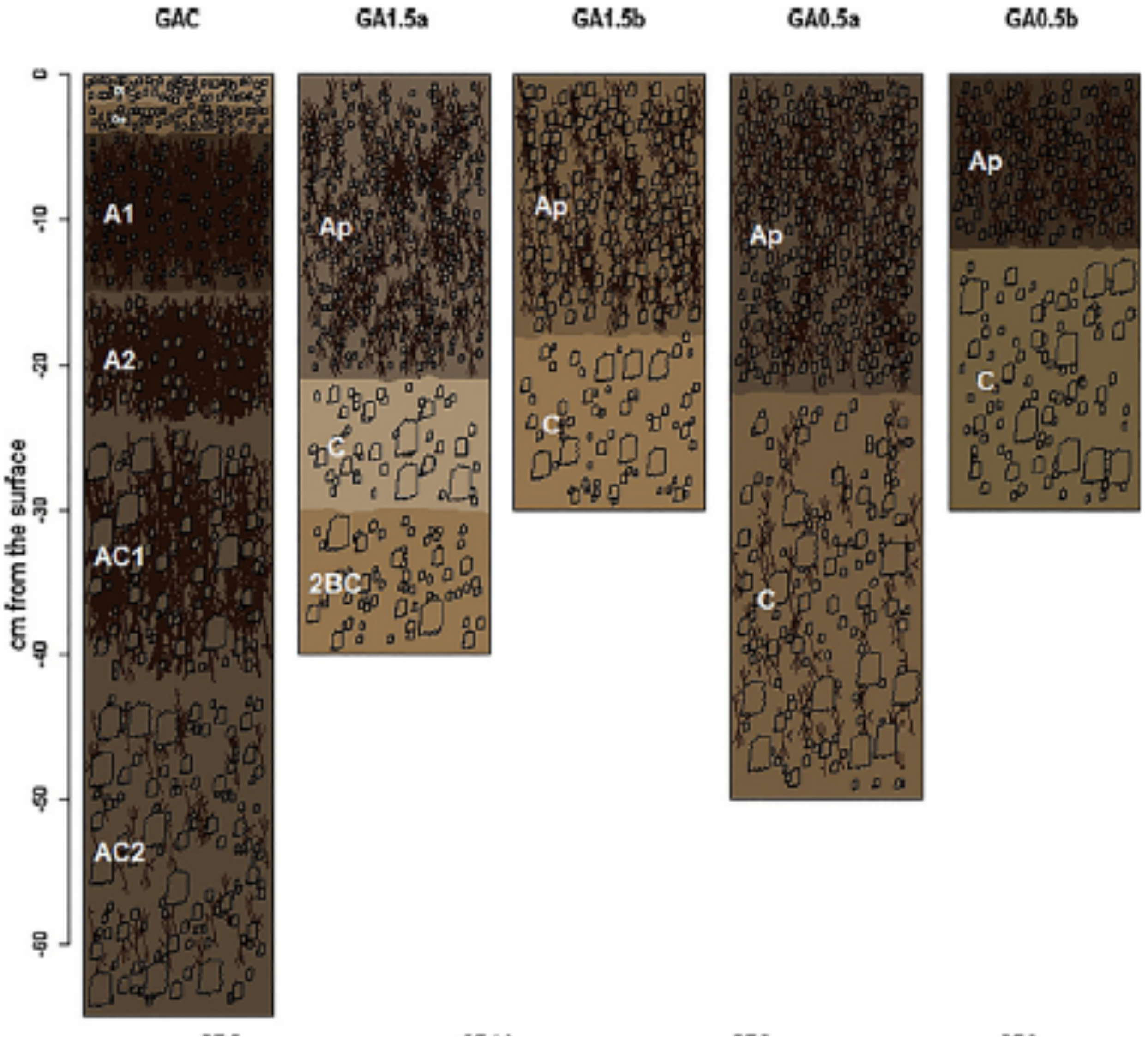
Fig. 1 The study areas in the North-Western Italian Alps. The gray-coloured magnified portion represents the Aosta Valley Region where AO indicates the city of Aosta. Abbreviations indicate the study sites: Gaby – GA, Verrayes – VE, Saint-Denis – SD.

Fabienne Curtaz , Silvia Stanchi , Michele E. D’Amico , Gianluca Filippa , Ermanno Zanini , Michele Freppaz

Soil evolution after land-reshaping in mountains areas (Aosta Valley, NW Italy)

Agriculture, Ecosystems & Environment, Volume 199, 2015, 238 - 248

http://dx.doi.org/10.1016/j.agee.2014.09.013


GAC
GA1.5a
GA1.5b
GA0.5a
GA0.5b
cm from the surface
0
-10
-20
-30
-40
-50
-60
Oe
A1
A2
AC1
AC2
Ap
C
2BC
Ap
C
Ap
C
Ap
C

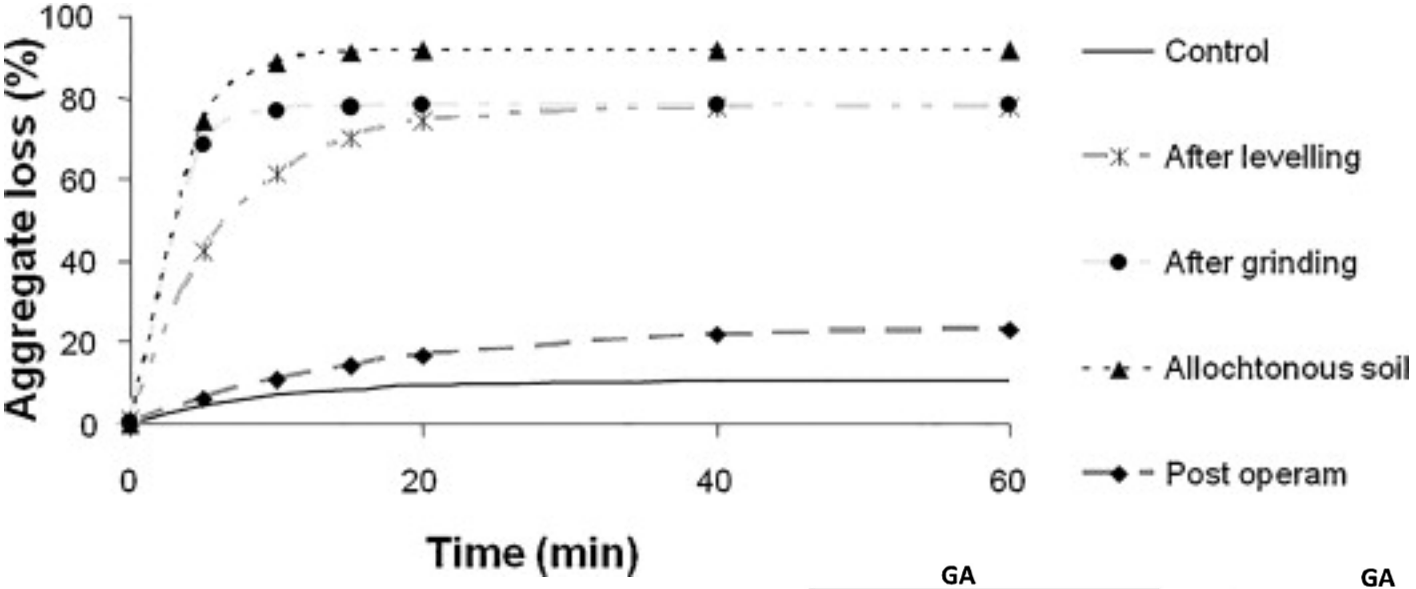
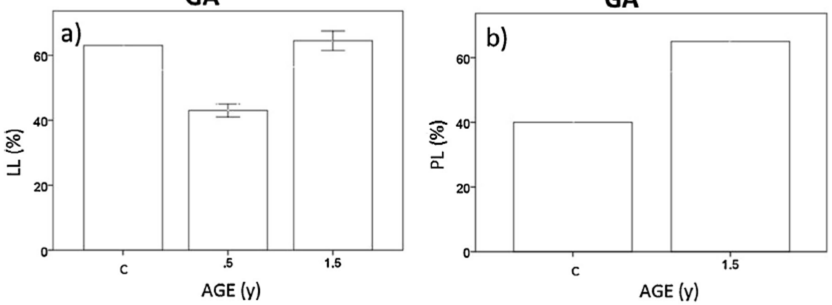


Fig. 5 Example of aggregate breakdown curves in the GA site.



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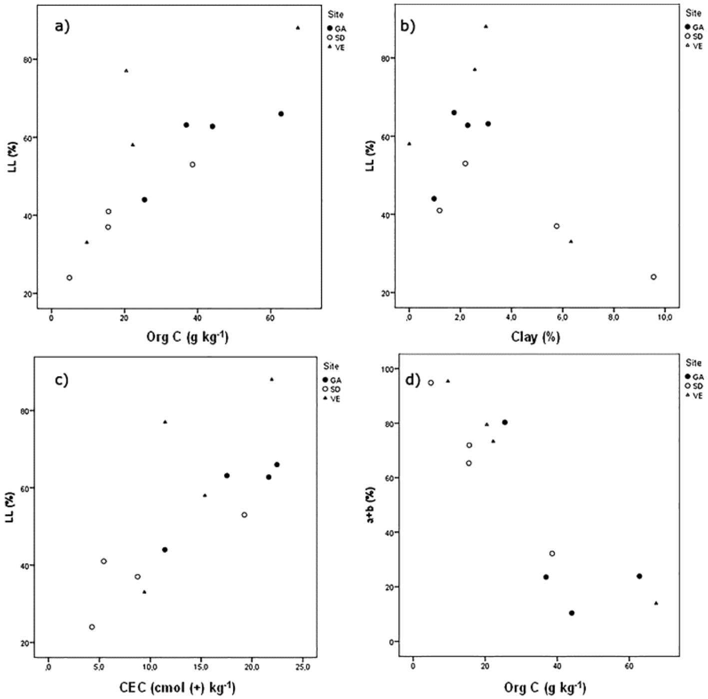

Fig. 7 Relationships between the liquid limit (LL) and TOC (a), clay fraction (b), CEC (c) and between total aggregate loss (a + b) and TOC in topsoil samples (*n* = 12).

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Erosion policies: some examples

- USA: starting in the ‘20 – ’30 (soil conservation movement)

- EU Soil Thematic Strategy: soil erosion is recognised as a «soil threat» for soil conservation and functioning (primary production, fertility and water conservation, habitat and biodiversity, heritage for humans).

Erosion estimation in mountain areas - empirical models

USLE Wishmeyer e Smith (1978)
RUSLE Renard (1997)

$$A = R \times K \times LS \times C \times P$$

- Erosion rate = t ha^{-1} y^{-1} ;
- R = *rainfall erosivity[MJ mm* h^{-1} ha^{-1} y^{-1}*];*
- K = *soil erodibility [t ha h* ha^{-1} MJ^{-1} mm^{-1}*];*
- LS = *slope length factor (-);*
- C = *land cover (-)*
- P = *control practices (- between 0-1).*

RUSLE applications (1 - Australia)

Study area

Normanby catchment, Cape York, Australia, 4 different geologies, 11 plots (0.1-9 Ha) , wet season (Nov-Apr)

Aim: quantifying soil erosion for catchment and river management

Methods

Sediment traps: 0.03–256 kg/ha/yr vs. RUSLE

Results

RUSLE provides over-estimation

Possible reasons: 1) K factors have been incorrectly extrapolated from empirical data collected elsewhere on agricultural soils that vary greatly from the typical savannah rangeland soils

2) Role of skeleton not adequately represented in either the C or K factor,

3) the model assumes that sediment supply is a linear function with time, when in fact the K factor (and hence supply) is likely to be non-linear

4) the vegetative cover factors applied in previous modeling have used the late dry season

C values.

Brooks et al., 2014. Measured hillslope erosion rates in the wet-dry tropics of Cape York,

northern Australia: Part 2, RUSLE-based modeling significantly over-predicts hillslope sediment production. Catena 122, 1-17.

RUSLE applications (2 - India)

Study area

Kerala (India) – a mountainous sub-watershed

Aim

Erosion estimate at watershed level

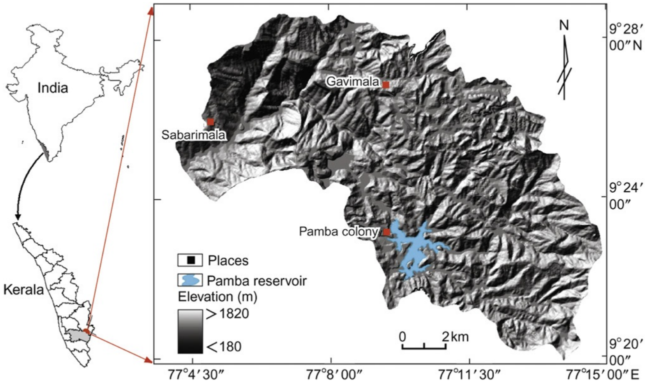
Methods

GIS-based RUSLE

Results

Map of annual soil erosion (max soil loss of 17.73 t h^{-1} y^{-1}) in grassland, degraded forests and deciduous forests on the steep side-slopes (high LS).

Prasannakumar et al., 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology *Geoscience frontiers 3, 209-215.*



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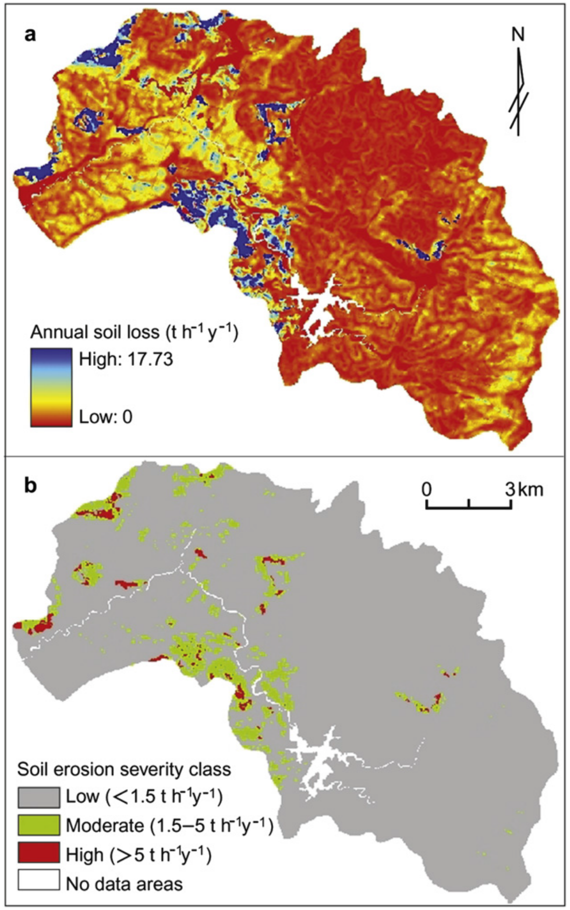


RUSLE applications (3 - Vietnam)

Study area

Lo River (Vietnam)

Aim

Catchment erosion estimate

Methods

- GIS-based RUSLE
- Sediment accumulation scheme to model suspended sediment load in the Lo basin at a monthly scale
- LUC simulation

Results

LUC scenarios were applied assuming that 20% of forest area is converted into rice and agricultural crops and 15% into bushes, shrubs and meadows

determined a 28% increase in suspended sediment load.

Also agricultural and hillslope maintenance practices can modify sediment erosion.

Ranzi et al., 2012. A RUSLE approach to model suspended sediment load in the Lo river (Vietnam):

Effects of reservoirs and land use changes. Journal of Hydrology 422-423, 17-29.

RUSLE applications (3 - Vietnam)

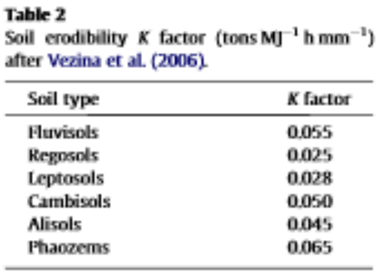


Table 2
Soil erodibility *K* factor (tons MJ^{-1} h mm^{-1}) after Vezina et al. (2006).

Soil type	*K* factor
Fluvisols	0.055
Regosols	0.025
Leptosols	0.028
Cambisols	0.050
Alisols	0.045
Phaozems	0.065

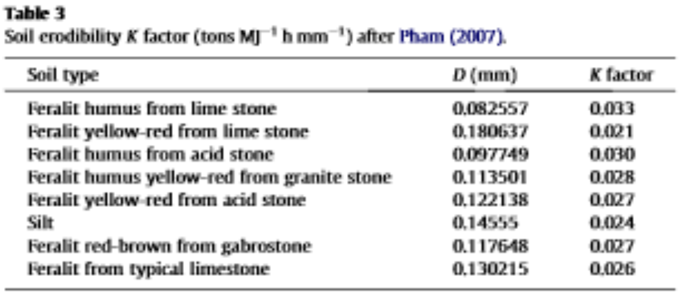
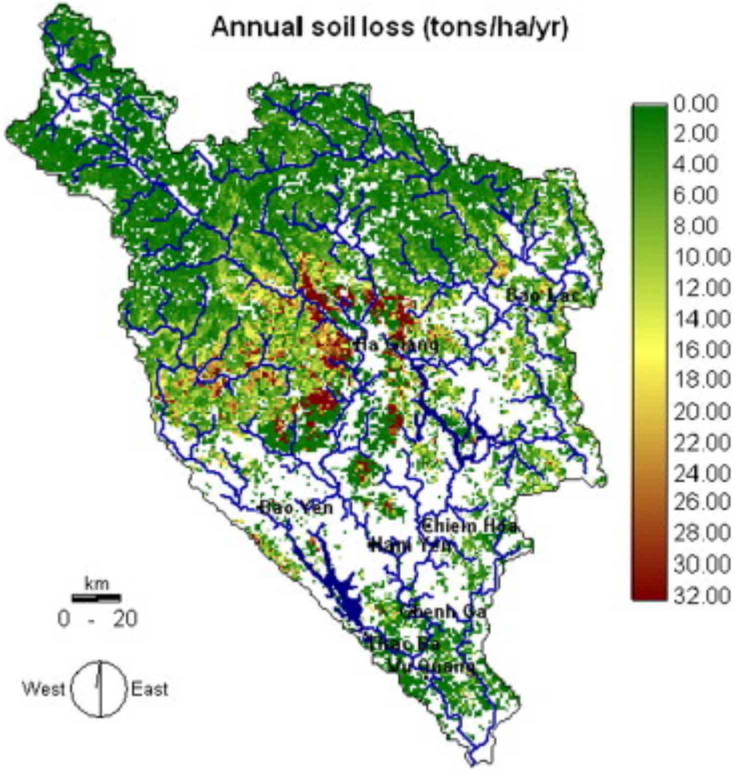


Table 3
Soil erodibility *K* factor (tons MJ^{-1} h mm^{-1}) after Pham (2007).

Soil type	*D* (mm)	*K* factor
Feralit humus from lime stone	0.082557	0.033
Feralit yellow-red from lime stone	0.180637	0.021
Feralit humus from acid stone	0.097749	0.030
Feralit humus yellow-red from granite stone	0.113501	0.028
Feralit yellow-red from acid stone	0.122138	0.027
Silt	0.14555	0.024
Feralit red-brown from gabrostone	0.117648	0.027
Feralit from typical limestone	0.130215	0.026



RUSLE applications (4 – Hymalaian region)

Study area

India

Aim

Catchment erosion estimate for planning and mitigation purposes. Comparing tolerant vs estimated erosion rates

Methods

GIS-based USLE

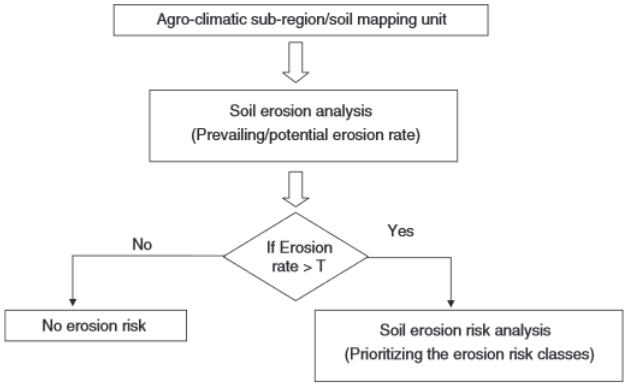


Figure 1. A summary scheme of prioritising the erosion risk classes.

Table I. Priority classes of erosion risks

Priority class	$(E-T)$ $(\mathrm{tha}^{-1}\mathrm{y}^{-1})$	Remarks
1	>35	Needs special soil and water-conservation measures
2	25–35	High priority for soil conservation
3	15–25	Medium priority for soil conservation
4	5–15	Less priority for soil conservation
5	0–5	Much less priority for soil conservation
6	<0	Requires no treatment
7	Non-soil area	Rock outcrops, glaciers, sand dune, etc.

Class 1 to class 5 represent the priority order. Class 6 represents the areas requiring no treatment as the difference between *E*- and *T*-values is less than zero, and the non-soil areas in the country are covered in class 7.

Mandal & Sharda, 2013. APPRAISAL OF SOIL EROSION RISK IN THE EASTERN HIMALAYAN REGION OF INDIA FOR SOIL CONSERVATION PLANNING. Land Degrad. Develop. 24, 430-437.

RUSLE applications (4 – Hymalaian region)

Results
A large part of the area has critical erosion rates

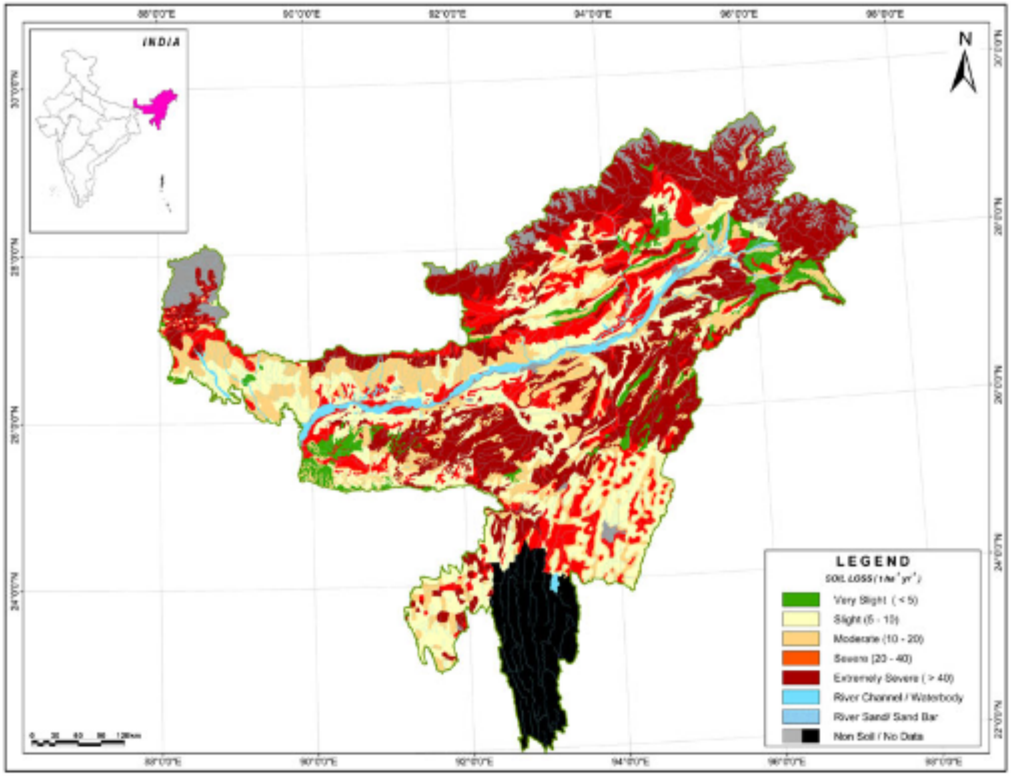


Figure 2. Soil erosion classes in the eastern Himalayan region of India. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Mandal & Sharda, 2013. APPRAISAL OF SOIL EROSION RISK IN THE EASTERN HIMALAYAN REGION OF INDIA FOR SOIL CONSERVATION PLANNING. Land Degrad. Develop. 24, 430-437.

RUSLE applications (4 – Hymalaian region)

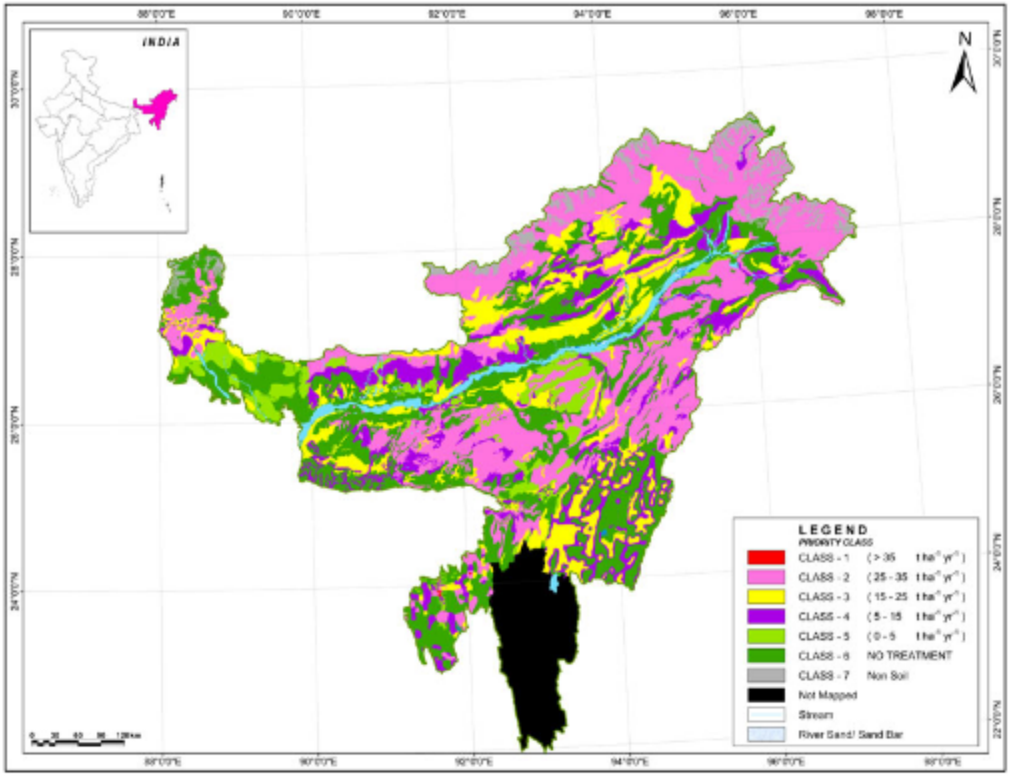


Figure 4. Priority classes for soil erosion control in the eastern Himalayan region of India. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Mandal & Sharda, 2013. APPRAISAL OF SOIL EROSION RISK IN THE EASTERN HIMALAYAN REGION OF INDIA FOR SOIL CONSERVATION PLANNING. Land Degrad. Develop. 24, 430-437.

RUSLE applications (5 – Tanzania)

Study area
Kondoa area
Aim
Erosion assessment through decades
Methods
GIS-based USLE

Ligonja & Shrestha, 2015. SOIL EROSION ASSESSMENT IN KONDOA ERODED AREA IN TANZANIA USING UNIVERSAL SOIL LOSS EQUATION, GEOGRAPHIC INFORMATION SYSTEMS AND SOCIOECONOMIC APPROACH. Land Degrad. Dev. 26: 367, 379.

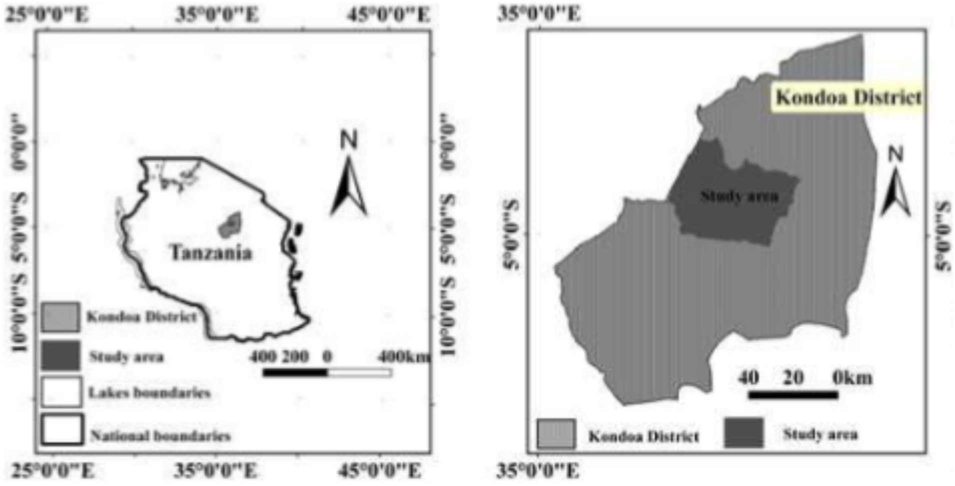


Figure 1. Location map of the study area.

RUSLE applications (5 – Tanzania)

Results

The predicted average soil erosions were 14.7, 23 and 15.7 Mg ha^{-1} y^{-1} during 1973, 1986 and 2008, respectively. The area under very high soil erosion severity that was 30% in 1973, 26% in 1986 and 25% in 2008, whereas the area with high erosion severity was 26% in 1973 changed into 49% in 1986 and 2008 indicating recent stabilization. The area with moderate erosion increased from 15%, 16% and 18% during the same period.

Ligonja & Shrestha, 2015. SOIL EROSION ASSESSMENT IN KONDOA ERODED AREA IN TANZANIA USING UNIVERSAL SOIL LOSS EQUATION, GEOGRAPHIC INFORMATION SYSTEMS AND SOCIOECONOMIC APPROACH. Land Degrad. Dev. 26: 367, 379.

RUSLE applications (6 - Andes)

Study area
Southern Andes of Ecuador
Aim
Erosion assessment and future scenarios
Methods
GIS-based RUSLE and LUC models

Ochoa-Cueva et al., 2011. SPATIAL ESTIMATION OF SOIL EROSION RISK BY LAND-COVER CHANGE IN THE ANDES OF SOUTHERN ECUADOR. *Land Degrad. Dev.* DOI: 10.1002/ldr.2219

RUSLE applications (6 - Andes)

Results

Ochoa-Cueva et al., 2011. SPATIAL ESTIMATION OF SOIL EROSION RISK BY LAND-COVER CHANGE IN THE ANDES OF SOUTHERN ECUADOR. *Land Degrad. Dev.* DOI: 10.1002/ldr.2219

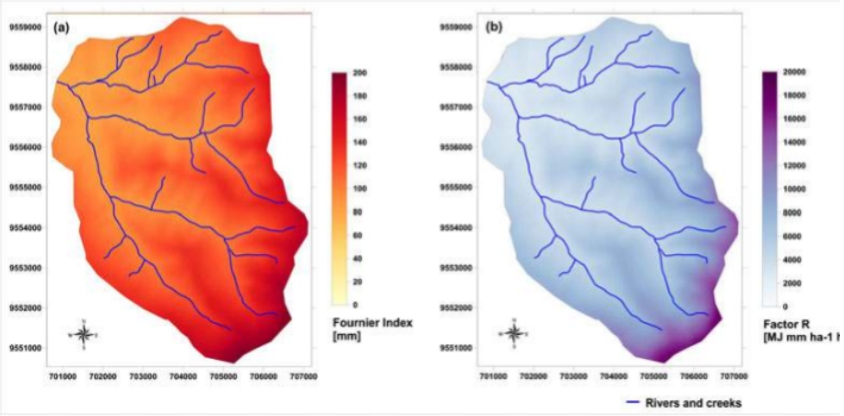


Figure 4. (a) Spatial distribution of MFI; (b) spatial distribution of annual *R*-factor. This figure is available in colour online at wileyonlinelibrary.com/

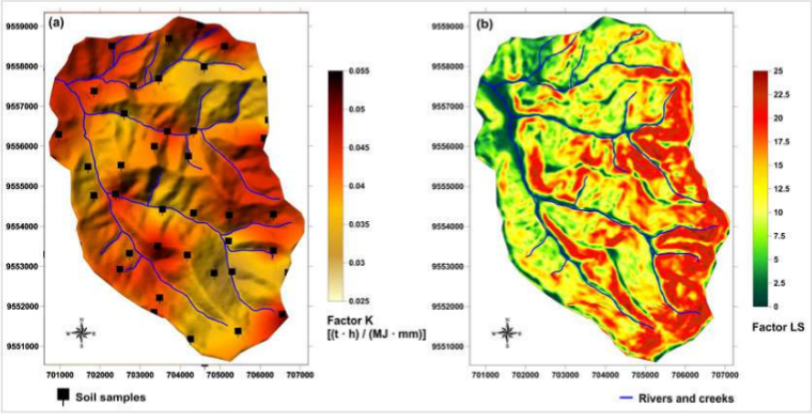
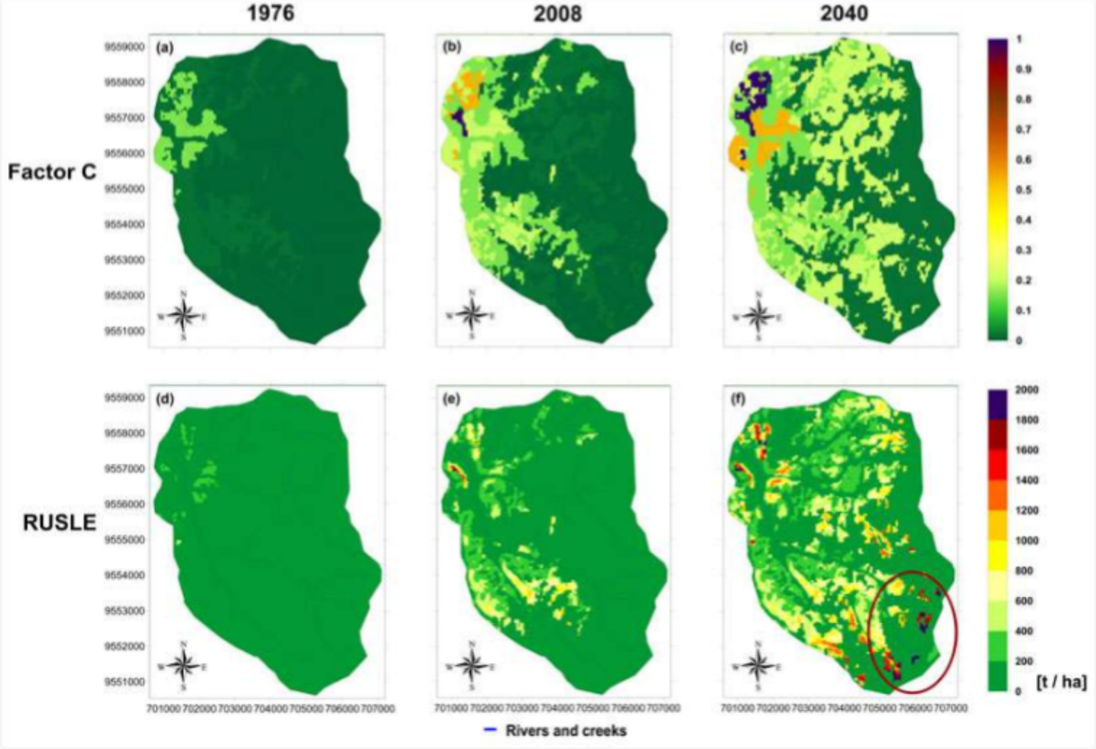


Figure 5. (a) Spatial distribution map of *K*-factor; (b) spatial distribution map of *LS* factors. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

RUSLE applications (6 - Andes)

Results
Very high predicted losses.
C factor seems to be the most relevant despite the importance which is generally attributed to R and LS.

Ochoa-Cueva et al., 2011. SPATIAL ESTIMATION OF SOIL EROSION RISK BY LAND-COVER CHANGE IN THE ANDES



Erosion estimation in mountain areas - radionuclides

- Radionuclides (e.g. ^{137}Cs) provides soil redistribution budgets after Chernobyl accident (1986) in the areas affected by radioactive fallout
- Cs is strongly associated with fine soil particles, therefore present-day Cs distribution may evidence erosion and deposition processes.

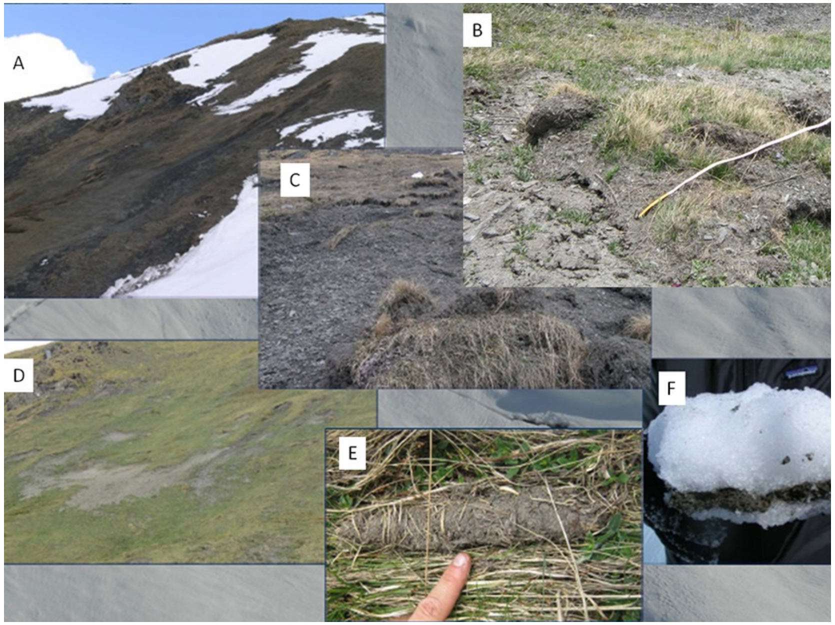
Erosion estimation in mountain areas - field measurements

- Sediment collection (traps, cups, other collection systems)

for seasonal, annual or event-based measurements, and model validation

Comparing different approaches in Alpine areas

- Importance of winter erosion in seasonally snow-covered areas
- Comparison between Cs-estimates and RUSLE modelling
- Derivation of a correction factor (W – winter factor)



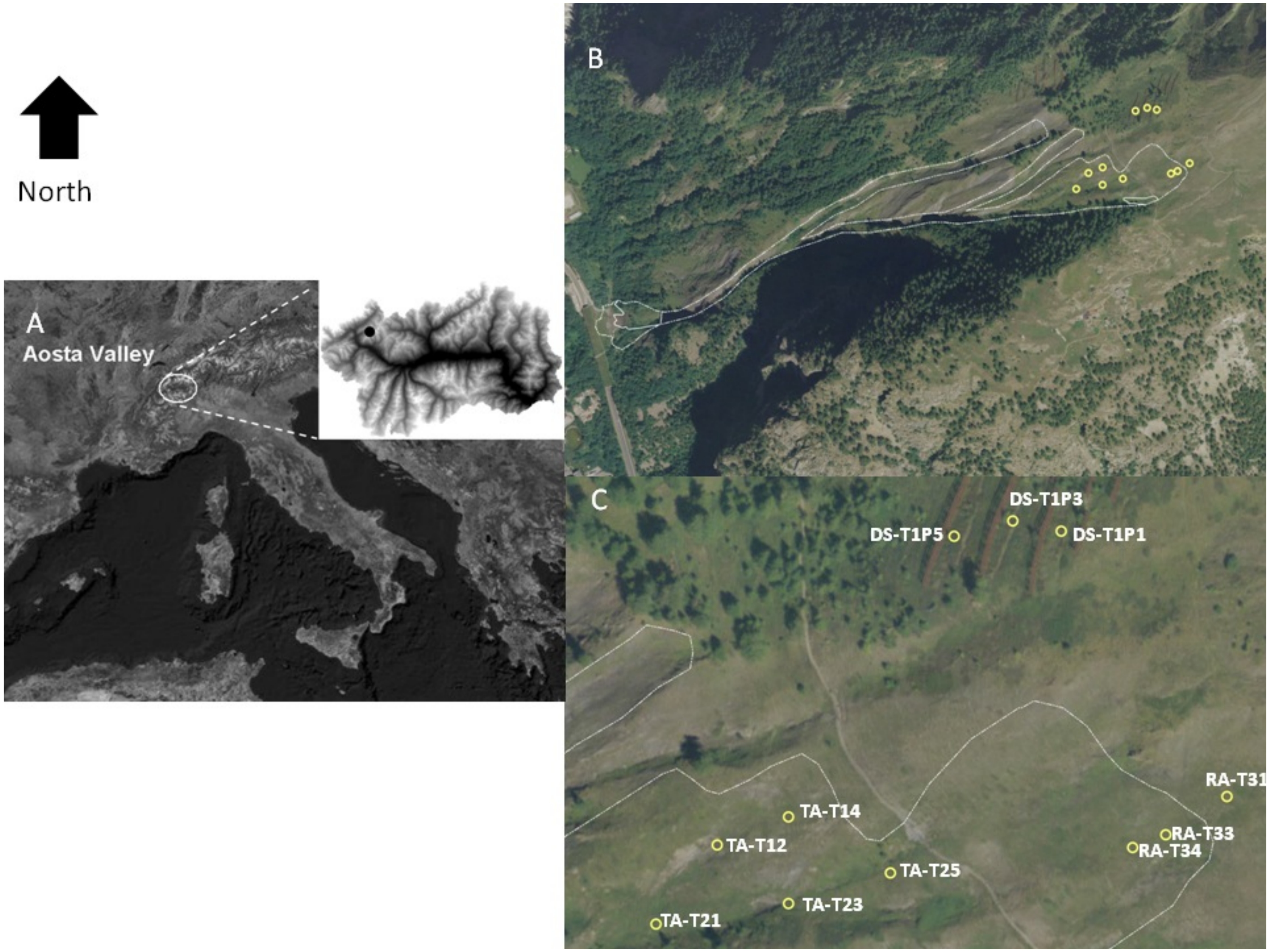
Nat. Hazards Earth Syst. Sci., 14, 1761–1771, 2014
www.nat-hazards-earth-syst-sci.net/14/1761/2014/
doi:10.5194/nhess-14-1761-2014

Natural Hazards and Earth System Sciences
Open Access

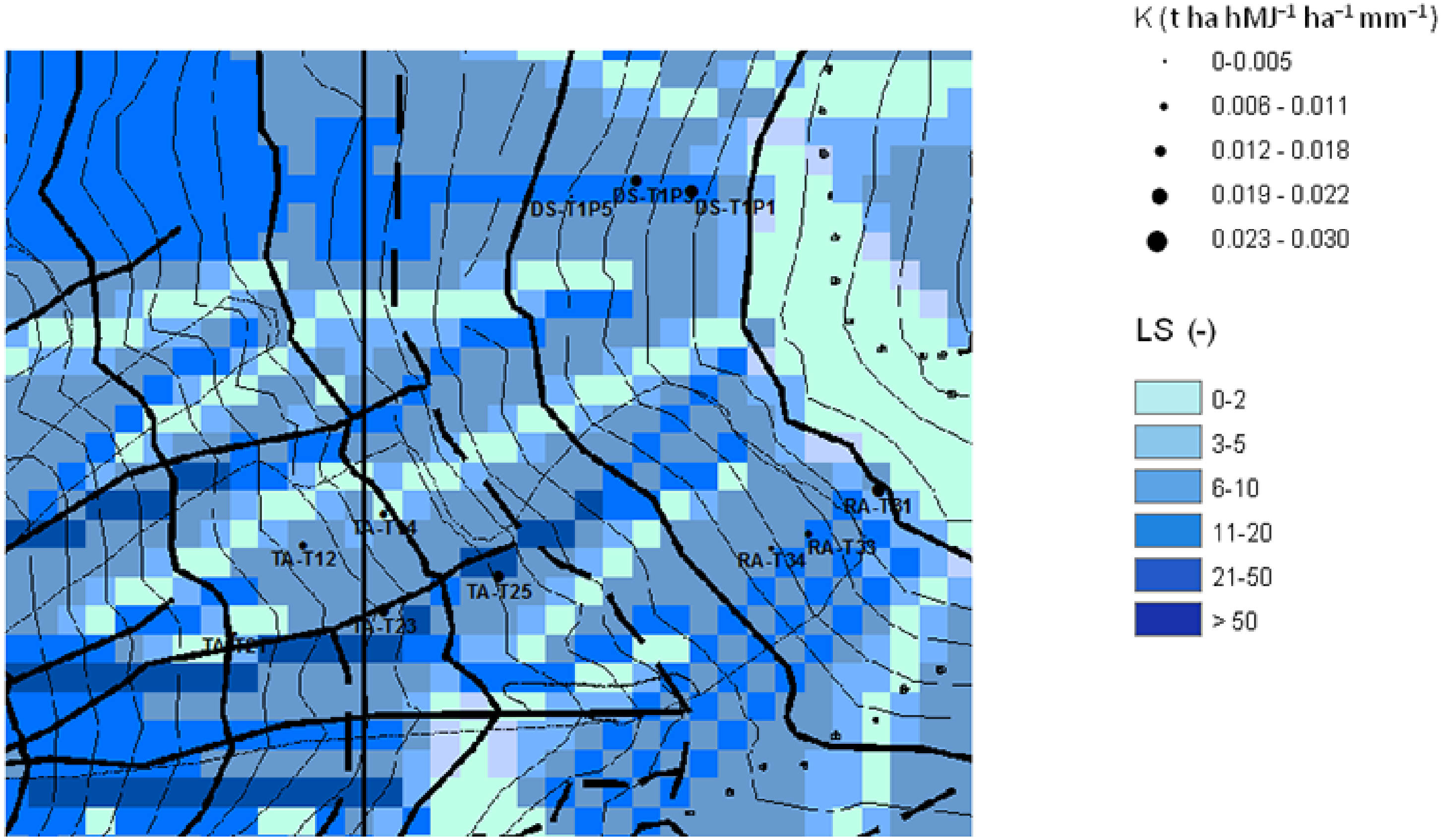
Soil erosion in an avalanche release site (Valle d'Aosta: Italy): towards a winter factor for RUSLE in the Alps

S. Stanchi[1,2], M. Freppaz[1,2], E. Ceaglio[3], M. Maggioni[1,2], K. Meusburger[4], C. Alewell[4], and E. Zanini[1,2]

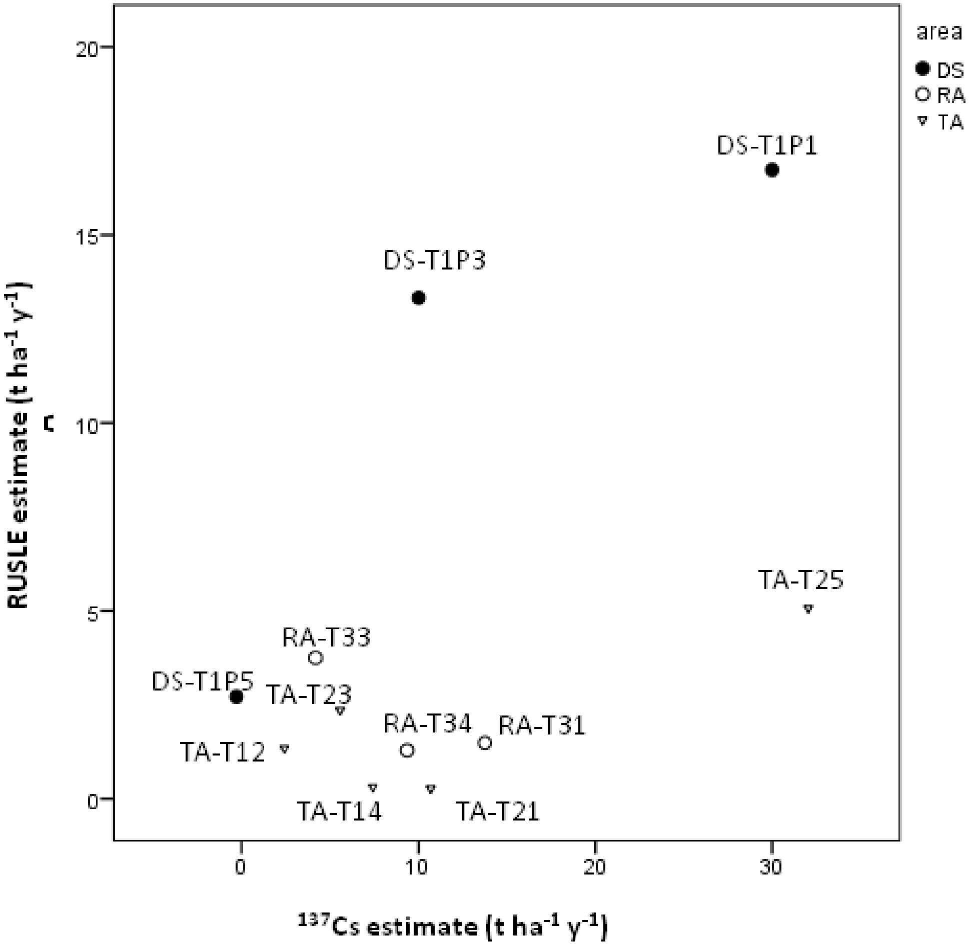
Study area


North
A
Aosta Valley
B
C
DS-T1P3
DS-T1P5
DS-T1P1
RA-T31
TA-T14
RA-T33
TA-T12
RA-T34
TA-T25
TA-T23
TA-T21

Effect of topography



Cs vs. RUSLE estimate



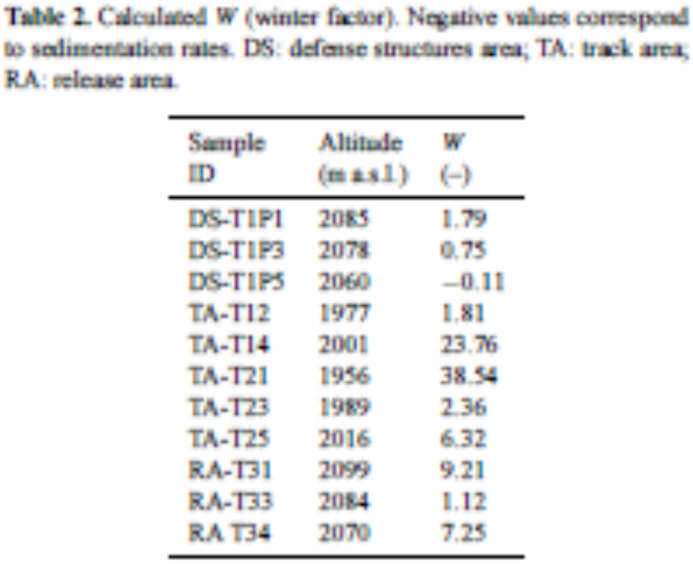
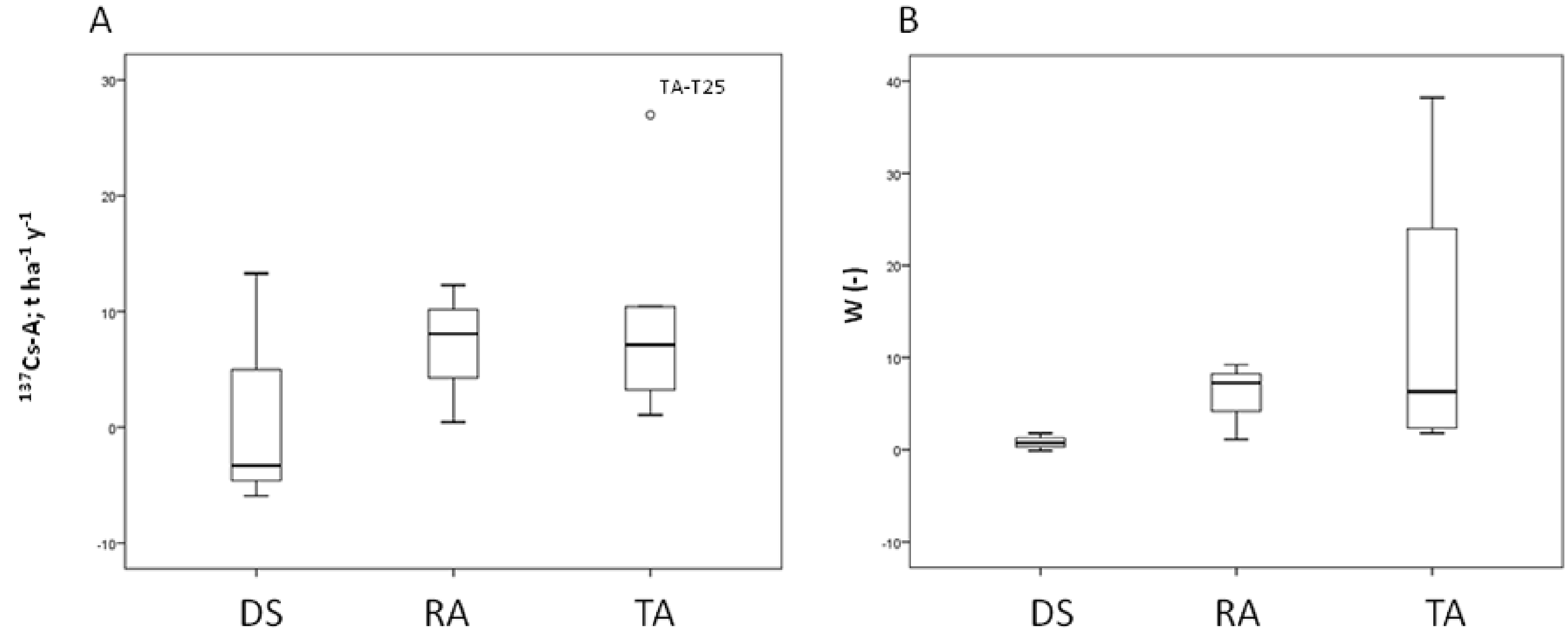


Table 2. Calculated *W* (winter factor). Negative values correspond to sedimentation rates. DS: defense structures area; TA: track area; RA: release area.

Sample ID	Altitude (m a.s.l.)	*W* (–)
DS-T1P1	2085	1.79
DS-T1P3	2078	0.75
DS-T1P5	2060	–0.11
TA-T12	1977	1.81
TA-T14	2001	23.76
TA-T21	1956	38.54
TA-T23	1989	2.36
TA-T25	2016	6.32
RA-T31	2099	9.21
RA-T33	2084	1.12
RA T34	2070	7.25

W factor


A
^{137}Cs-A; t ha^{-1} y^{-1}
30
20
10
0
-10
TA-T25
DS
RA
TA
B
W (-)
40
30
20
10
0
-10
DS
RA
TA

Final remarks

- Relevance of erosion impacts (on-site and off-site)
- Difficulty in predicting erosion, mainly in topographic complex, non-agricultural areas
- Importance of the estimation model choice
- Need for validation and field measurement

Further reading

- Morgan, R. P. C., Soil erosion and conservation / R. P. C. Morgan. – 3rd ed. 2005.

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