Event-based soil erosion and sediment yield modeling for calculating long-term reservoir sedimentation in the Alps

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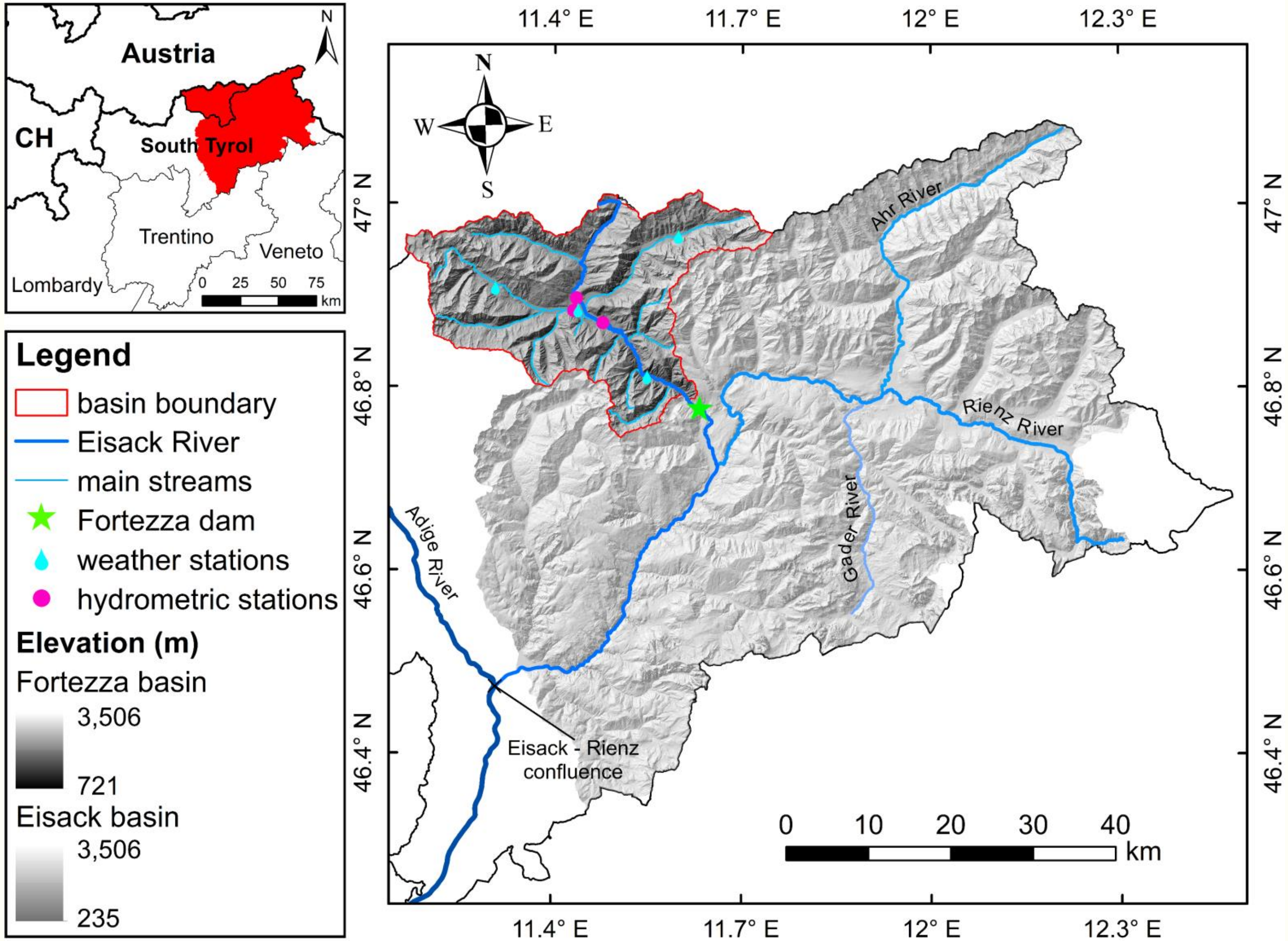
Highlights

- A modified USLE-based model, ideal for upper-lands and mountain areas
- Adaptation of the topographic factor (LS) for the alpine terrain
- The proposed SDR module resulted in sediment yields equal to 27.4% of gross erosion
- High spatial resolution (2.5m) soil erosion modeling
- Reservoir sedimentation 143,355.3 tons – validation with measurements

Study area



- Area = 655.8 km^2
- Mean slope = 30.5° (max = 87.4°)
- Mean altitude = 1,869 m
- Temperature = –22.0 °C to 38.5 °C
- Pluvo-nival flow regime

USLE for mountain areas

- ❑ Addition of a seventh factor to the conventional six-factor USLE
- ❑ Considering the % of rock in the soil surface

$$F_{CFRG} = e^{-0.053 \cdot rock}$$

⬇

$$A = R_r \times K \times LS \times C \times P \times F_{CFRG}$$

(Box and Meyer, 1984; Williams, 1995)

where F_{CFRG} = Coarse Fragment factor
rock = rock in the soil surface (%)

USLE specific features

Adaptation of the L-factor for the Alpine environment

- Flow length threshold of 100m (Schmidt et al., 2019)

$$\begin{aligned} A_{\text{alpine } i,j-in} &= \text{thresh}, \quad A_{i,j-in} > \text{thresh} \\ A_{\text{alpine } i,j-in} &= A_{i,j-in}, \quad A_{i,j-in} \le \text{thresh} \end{aligned} \Rightarrow L_{\text{alpine } i,j} = \frac{\left(A_{\text{alpine } i,j-in} + D^2\right)^{m+1} - A_{\text{alpine } i,j-in}^{m+1}}{D^{m+2} \cdot X_{i,j}^{m} \cdot 22.13^{m}}$$

S-factor

$$S = 10.8 \cdot \sin\Theta + 0.03, \quad \text{slope gradient} < 0.09$$

$$S = 16.8 \cdot \sin\Theta - 0.5, \quad \text{slope gradient} \ge 0.09$$

(McCool et al., 1987)

where $A_{i,j-in}$ = contributing area at the inlet of grid cell (i,j) (m^2); D = size of the grid cell (m); $X_{i,j} = \sin a_{i,j} + \cos a_{i,j}$
$a_{i,j}$ = aspect direction of the grid cell (i,j); m = slope length exponent; Θ = slope steepness in radians

Rainfall erosivity (R-factor) calculation

Event R-factor

$$e_r = 0.29 \cdot \left[1 - \left(0.72 \cdot e^{-0.05 \cdot i_r}\right)\right]$$

$$R_{event} = EI_{30} = \left(\sum_{r=1}^{k} e_r \cdot v_r\right) \cdot I_{30} \quad (\text{MJ mm ha}^{-1}\ \text{h}^{-1}\ \text{event}^{-1})$$

Erosive rainfall events criteria

i) >6.35 mm – 15 min (Renard et al., 1997)

ii) MIT (minimum inter-event time) 6 h (Wischmeier and Smith, 1978)

e_r = unit rainfall energy (MJ ha^{-1} mm)	v_r = rainfall volume (mm)
i_r = rainfall intensity (mm h^{-1})	I_{30} = maximum rainfall intensity within 30 min of the event (mm h^{-1})
EI_{30} = rainfall event erosivity (MJ mm ha^{-1} h^{-1})	R_{event} = event rainfall erosivity (MJ mm ha^{-1} event^{-1})

Sediment Delivery Ratio (SDR) module

- A part of the eroded sediments is temporarily stored in the system before reaching the outlet
- Estimate the sediment yield delivered in downstream areas

$$\log(\mathrm{SDR}) = 2.94259 - 0.82362 \cdot \log\left(\frac{l}{\mathrm{RL}}\right)$$

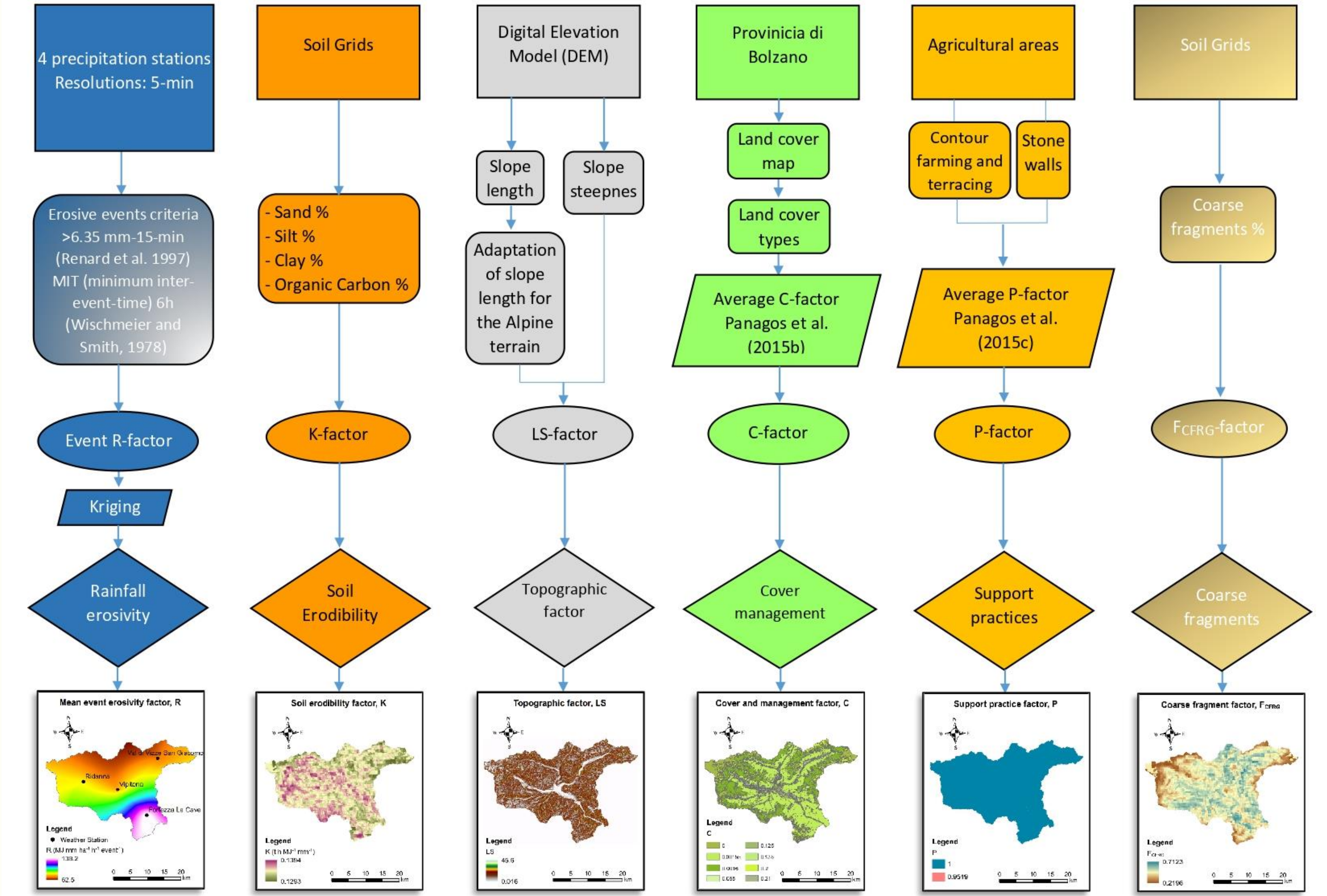
$$\log(\mathrm{SDR}) = 1.8768 - 0.14191 \cdot \log(10 \cdot \mathrm{FL})$$

$$\mathrm{SDR} = 0.627 \cdot J_s^{0.403}$$

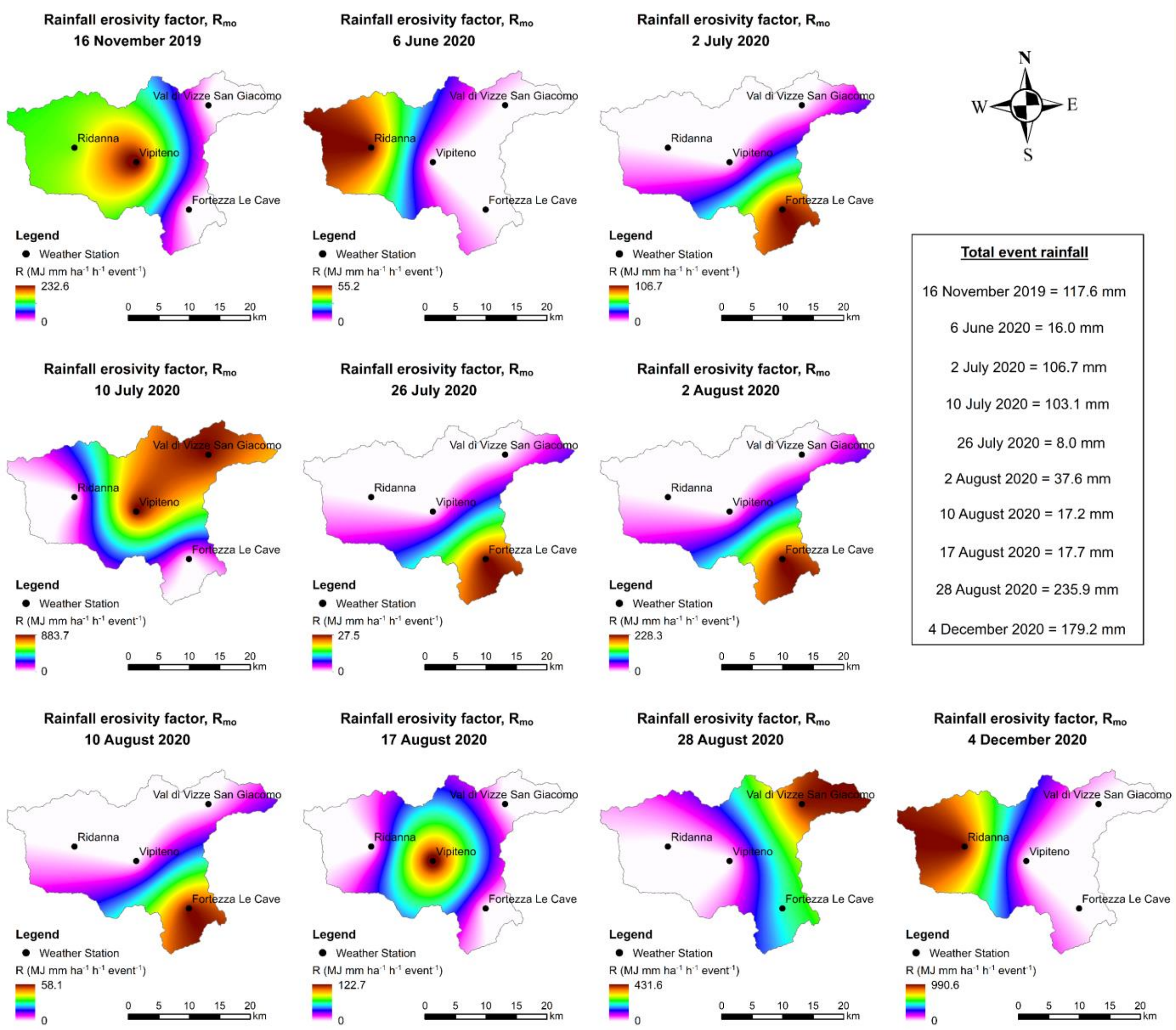
$$\mathrm{SDR} = 1.366 \cdot 10^{-11} \cdot \mathrm{FL}^{-0.0998} \cdot \left(\frac{\mathrm{RL}}{l}\right)^{0.3629} \cdot \mathrm{CN}^{5.444}$$

where SDR = sediment delivery ratio (%)
l = length of the main stream (m)
RL = alt. dif. of two ends of main stream (m)
FL = basin area (km^2)
J_s = mean bed slope of the main stream
CN = runoff Curve Number

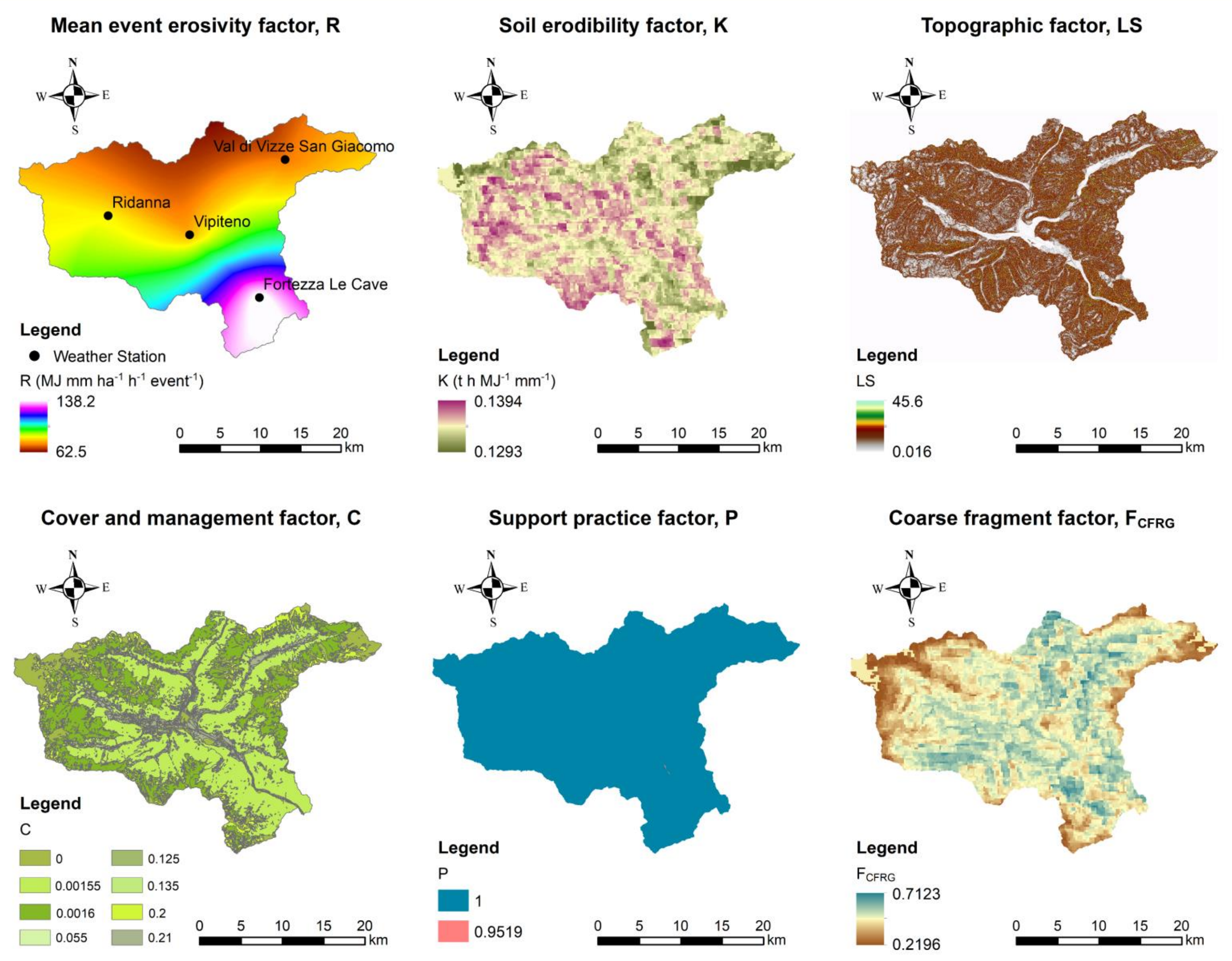
Input datasets



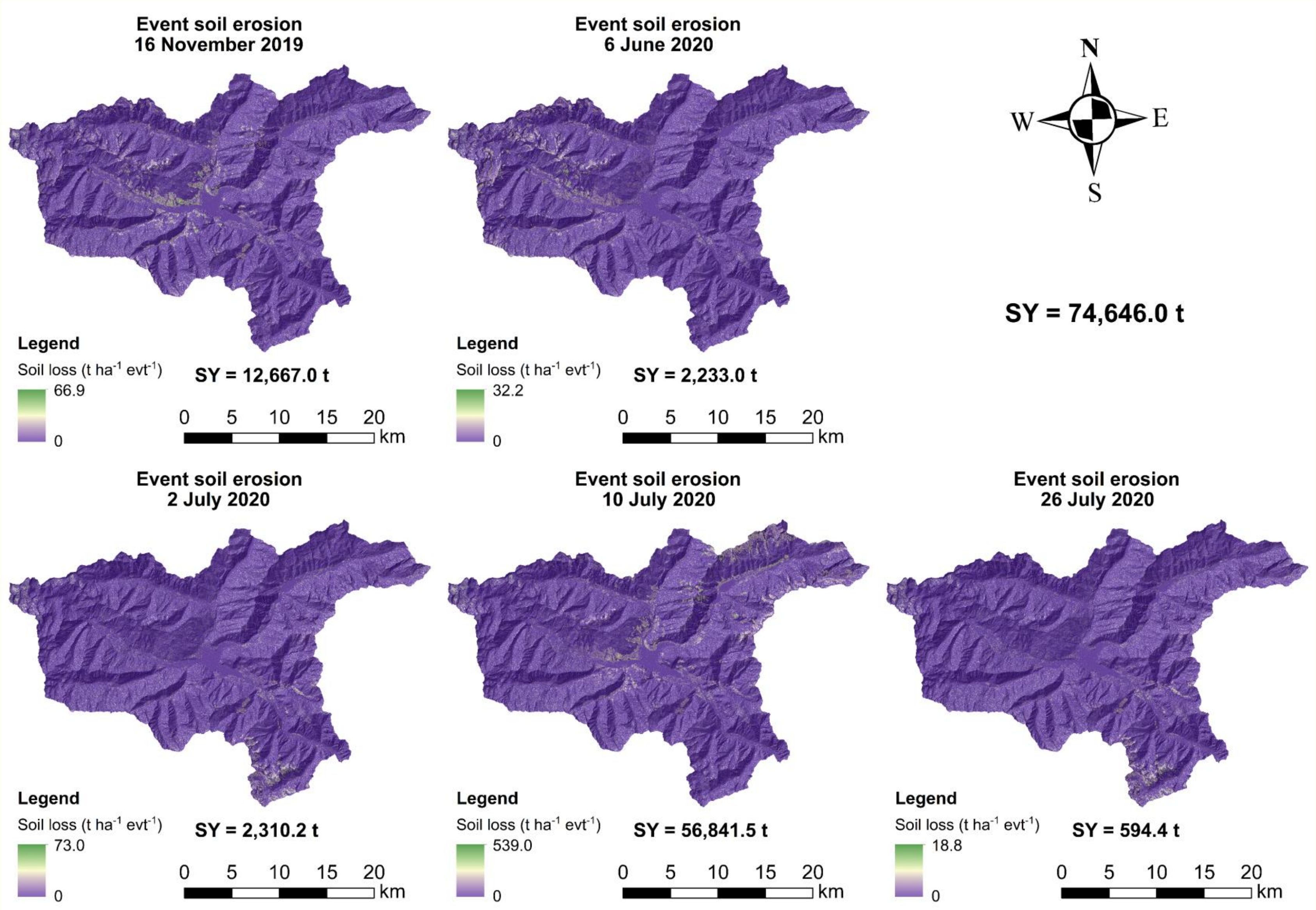
Event rainfall erosivity (R-factor)



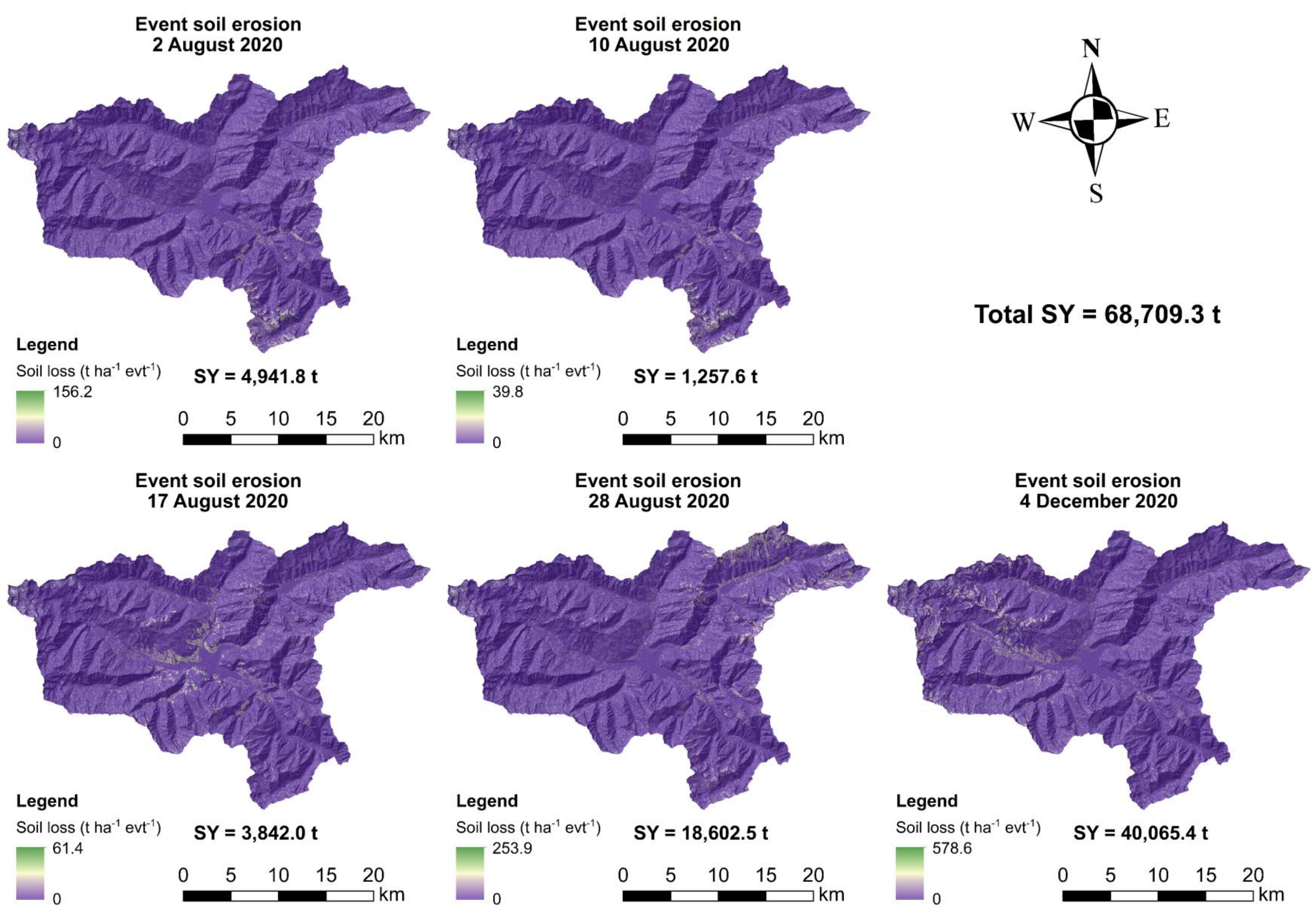
Results – USLE factors



Results – Soil erosion & SY

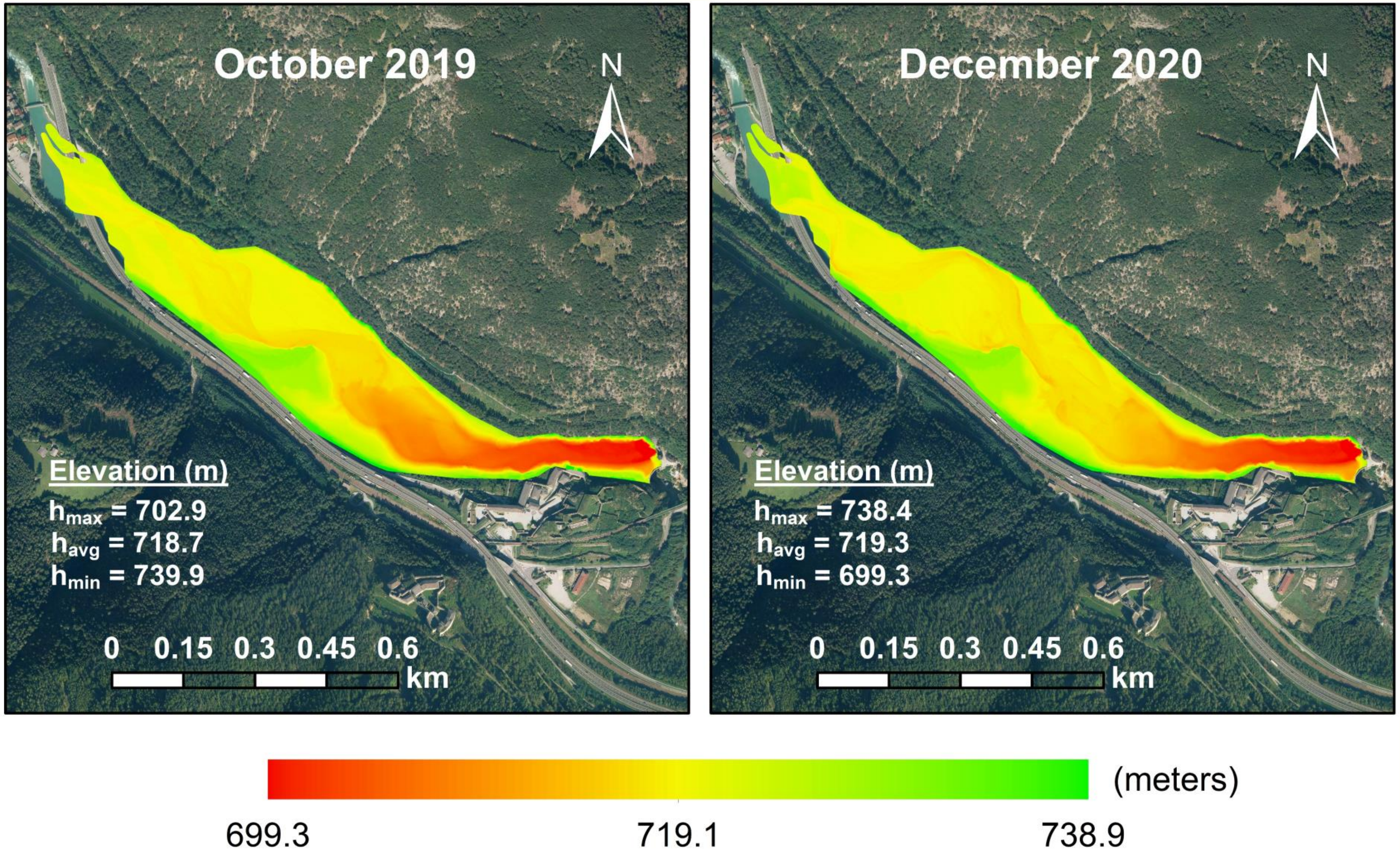


Results – Soil erosion & SY



Total SY = 143,355.3 t

Results – Bathymetric maps of the Fortezza reservoir



- Spat. resolution = 0.2 m
- Time frame = 14 months

Results – Volume difference – Measured SY

Volume difference = 131,199 m^3

Volume dredged = 30,000 m^3

Volume accumulated = 161,199 m^3

Dry bulk density = 0.702-0.747 t/m^3

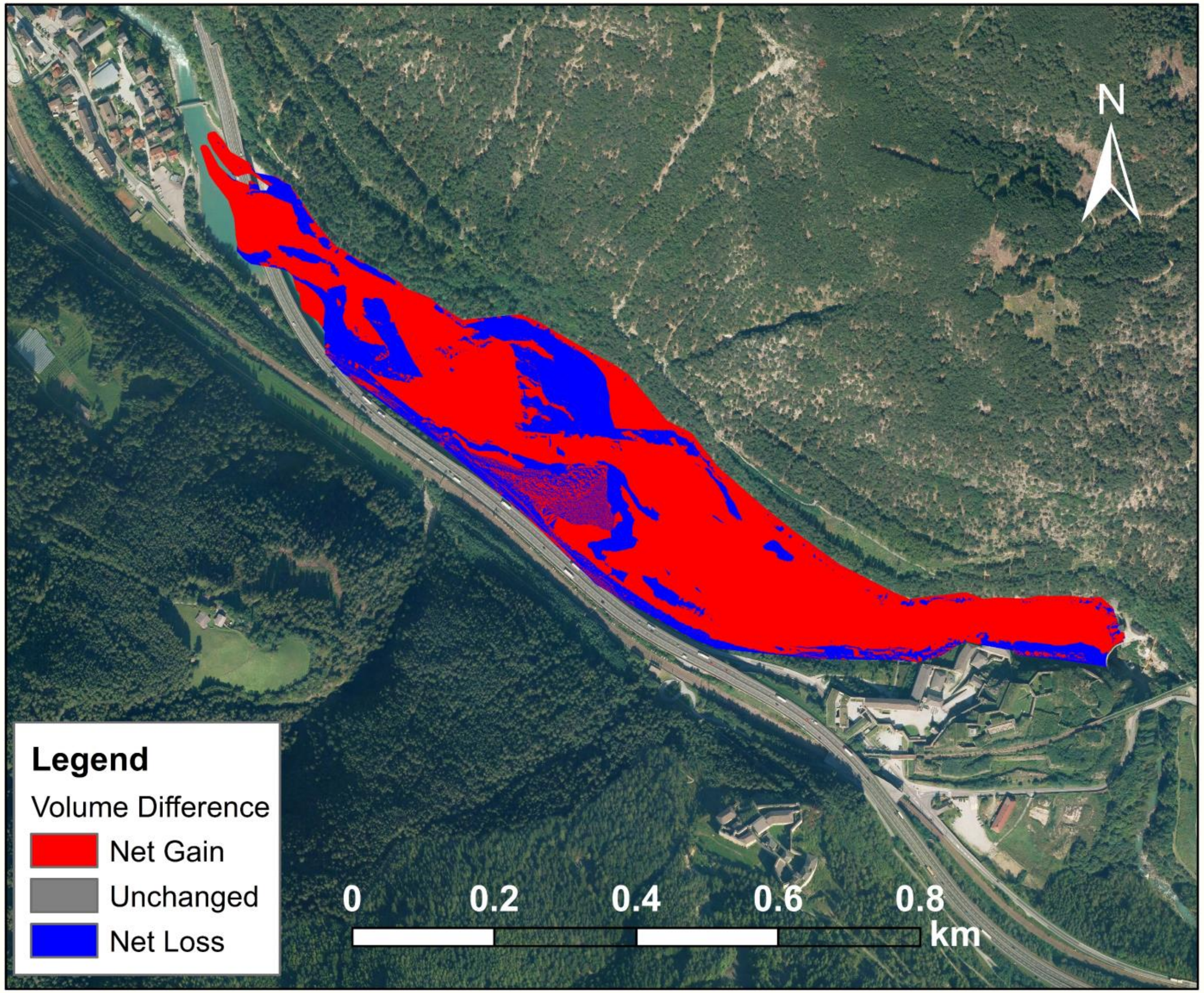
Sediment yield = 113,161.7-120,415.7 t

Mean measured SY = **116,789 t**

Calculated SY = **143,355.3 t**

–26.7% ≤ Deviation ≤ –19.1%

Deviation = **–22.7%**



THANK YOU FOR YOUR ATTENTION