Assessing and mapping soil-based ecosystem services of the Emilia-Romagna Apennines

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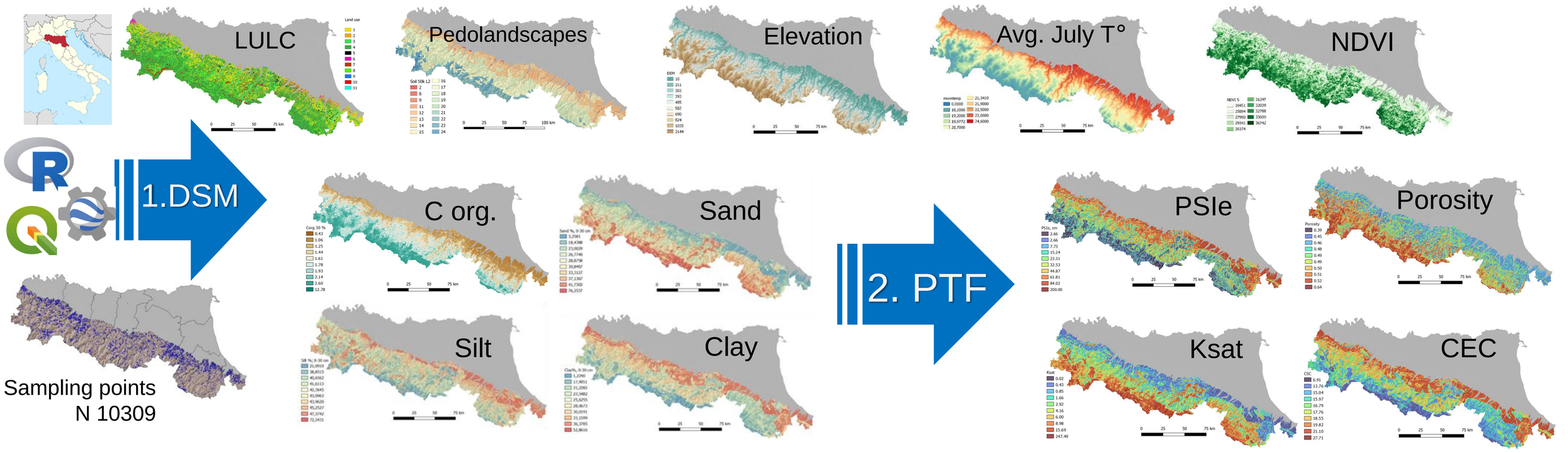
This work presents the results of the implementation of a methodological framework to assess and map the multiplicity of soil-based ecosystem services (SES), based on measured soil data (N = 10309) for a reference depth of 30 cm for the hilly and mountainous area (10532 km2) of Emilia-Romagna (NE Italy).

The methodology consists of: (i) definition of soil based eco-system services indicators (SES), based on available soil data and on societal demands; (ii) definition of appropriate indicators for SES potential supply based on measured soil data and derived soil properties; and (iii) biophysical assessment, computation of 0-1 normalised indicators and mapping of soil based multiple ecosystem services at a 100 m resolution.

We used spatial data to characterize and model the spatial heterogeneity of the following provisioning, supporting, and regulating SES resorting to Digital Soil Mapping (DSM) techniques: habitat for soil biodiversity (BIO), buffering capacity (BUF), carbon sequestration (CST), food provision (PRO), biomass provision (BIOMASS), erosion control (ERSPRO), water regulation (WAR) and water storage (WAS). To explicitly take into account the spatial variability and the related uncertainty, and to exploit at best the available information, we: (i) realized a continuous coverage (on a 100 m regular grid) of basic soil properties (coarse fragments, sand, silt and clay fractions, organic carbon content, pH) via Quantile Random Forest (QRF) resorting to categorical and continuous covariates available over the entire area, and (ii) derived the soil properties at the basis of the soil functions underpinning potential ES supply (e.g. bulk density, porosity, retention properties, hydraulic conductivity) via locally calibrated pedotransfer functions (PTFs).

DSM of basic and derived soil properties



SES Assessment and Mapping

Ecosystem Services[a]	Code CICES 5.1	Soil contribution to ES	Soil functions	Indicators	Input data	Code
Regulating	2.2.1.1 2.3.3.2	Nutrients/pollutants retention and release Filtering capacity (potential)	Storage, filtering and transformation of nutrients/pollutants and water	CEC Soil pH	C org % Clay % pH Skel %	BUF
Regulating	2.1.1.2 2.3.3.2	Carbon stock (potential)	Carbon pool	Actual C sequestration	C org % Bulk density	CST
Regulating	2.2.1.1 2.2.1.3	Reduction of soil losses due to water erosion	Support to vegetation	Actual erosion	RUSLE factors C, K, LS, R	ERSPRO
Provisioning	1.1.1.1	Food provision (potential)	Biomass production (food)	Soil capability map	LCC e integrades	PRO
Provisioning	1.1.1.x 1.1.5.x	Biomass provision (potential)	Biomass production	NDVI, mean 2015-2020	NDVI (Landsat 8)	BIOMASS
Regulating	2.2.1.3	Water regulation/runoff and flood control (potential)	Storage, filtering and transformation of nutrients and water	Infiltration capacity	Ksat (mm/h) Psi_e (cm)	WAR
Regulating (Provisioning)	2.2.1.3 (4.2.2.2)	Water regulation – water storage (potential)	Storage, filtering and transformation of nutrients and water	Water content at field capacity	Field capacity (-33 kPa)	WAS
Regulating	2.2.2.3	Habitat for soil organisms	Biodiversity pool	Habitat (potential) for soil organisms	QBS-ar Covariates DSM	BIO

3. SES

All indicators, with the exception of PRO, are rescaled to the 0-1 interval with the following:

$$X_{i\ 0\text{-}1} = (X_i - X_{min})/(X_{max} - X_{min})$$

SES	Input data	Indicators calculation
BUF	CEC (cmolc/kg) as function of OC (%) and clay (%) CEC = 6.332 +0.404 clay + 1.690 OC (R^2 = 0.75) pH Coarse fragments content, sk (%) Shallow water table depth, WT (cm)	BUF_{0-1} = Log CSC (pH; $sk)_{0-1}$ With pH<6.5 reduction by 0.25 or 0.5 depending on CEC and by 0.25 for skel. >30% With shallow water table depth (WT) < 30 cm BUF_{0-1} = Log CSC (pH; $sk)_{0-1}$*WT/30
CST	Organi carbon, OC (%) Bulk density, BD (Mg m^{-3})	CST_{0-1} = log $[OC * BD * (1-SK)]_{0-1}$
ERSPRO	Potential soil erosion (Mg ha^{-1} y^{-1}) Actual soil erosion(Mg ha^{-1} y^{-1})	Standardization (0-1) Log10 (Potential erosion – actual erosion)
PRO	Capability class and intergrades	LCC class scaling (0-1)
BIOMASS	NDVI (Normaized Difference Vegetation Index)	Standardization (0-1) NDVI (mean of 2015-2020 median values)
WAR	Saturated hydraulic conductivity, Ksat (mmh^{-1}) Air entry potential PSIe (cm)	WAR_{0-1} = log$Ksat_{0-1}$–$PSIe_{0-1}$
WAS	Field capactity (-33 kPa), WCFC (vol/vol) Average shallow water table depth, WT (cm) Sk, coarse fragments (Ø >2 mm, vol/vol)	WAS_{0-1} = (WC_{FC} * 1–$sk)_{0-1}$ WT depth> 100 cm, and WAS_{0-1} = (WC_{FC} * 1-sk)*WT/100 with WT depth <100 cm
BIO	QBS_{ar} Covariates for Digital Soil Mapping	DSM approach (Quantile Random Forest)