



ACTION B.1.3

Guidelines for assessing soil ecosystem services in urban environment and their management

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1. INTRODUCTION

Urban soils are deeply influenced by human activities. They consist of materials different from those of nearby agricultural or natural areas, due to mechanical disturbance, supply or removal of material, contamination with exogenous materials (plastics, asphalt, pollutants, etc.). They are the result of urbanization activities that involve total or partial sealing of the surfaces (Morel et al. 2005).

The development of urban soils is controlled by the same factors as natural soils, with a clear and important prevalence of the anthropic factor. The survey of urban soils therefore follows the same criteria of surveying natural or agricultural soils, taking into account that the anthropic disturbance in addition to being prevalent acts in a very short time. This causes a strong heterogeneity in the spatial distribution of the soils and of their characteristics that is problematic to solve in a detailed soil map.

Human disturbed soils are classified (FAO World Reference Base For Soil Resources, IUSS - Working Group WRB, 2014) as:

• *Anthrosols*: soil that has been formed or heavily modified due to long-term human activity, such as from irrigation, addition of organic waste or wet-field cultivation used to create paddy fields

• **Technosols**: are dominated by their technical origin. They contain either a significant (20% or more) amount of artefacts or some sort of geotechnical liner, or are sealed by technic hard rock (hard material created by humans, having properties unlike natural rock).

Urban soils perform the same functions as a natural soil contributing to the provision of Ecosystem Services. However, the degree of disturbance to which they are subjected, the level of sealing and the type of coverage have an influence that needs to be described in detail and taken into account.

Given the great variability of the urban environment and the differences between different urban environments, there are still no standardized references for the survey and mapping of urban soils. There are experiences. the Berlin some such as the map of city of (https://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/dinh 01.htm) and New York City of (http://www.soilandwater.nyc/urban-soils.html).

Within the SOS4LIFE project, a methodology has been developed for defining urban soil mapping units in the study case of the town of Carpi (MO), based on the type of "natural" soils below the urban fabric, the urban typologies and the land cover of unsealed soils. Considering that most of the SEs in urban areas are provided by green areas, the assessment of soils and related functionality has been concentrated in gardens and parks, sports fields and on peri-urban agricultural areas. The gardens in private allotments were not considered, having verified the high degree of impermeabilization of the same (driveways, parking lots, access ramps to garages, etc.). However, even these soils, although strongly altered, maintain some functionalities. The SEs considered are therefore generally underestimated for the entire city.

2. ASSESSING SOIL BASED ECOSYSTEM SERVICES

2.1 Mapping urban soils

Prior knowledge of soils, of their properties and distribution in the urban space is required in order to assess and eventually map their ecosystem services (ESs). Depending on the goal of the investigation and on resources availability, the necessary soil data can results from *ad hoc* urban soil surveys or from existing soil databases and maps.



2.1.1 Ad hoc urban soil survey

Due to the high variability of urban soils and their characteristics, it is unlikely to define precisely soil typologies in urban areas. Standard soil surveying techniques are not suited for the urban environment and specific soil surveying techniques have to be followed. We need to have practical instruments able to support urban planning, taking into account the ESs provided by soils. These instruments need to be as simple as possible so that every municipality can easily adopt them in their planning policies.

Assuming that urban soils development is strongly affected by human activities, we can define "urban pedolanscape units" taking into account the "natural soils" underlying the town and its urbanistic structure, degree of sealing and land use. An example relative to the town of Carpi is shown in Figure 1.



Figure 1. Definition of preliminary urban pedolandscape units in the municipality of Carp, Emilia Romagna (NE Italy).

In this case, the different urban typologies have been overlaid to soil map (1:50,000) obtaining a number of preliminary urban pedolandscape units. Green areas soils must then be characterised according for each pedolandscape unit, taking into account the main land use types, e.g. i) urban agriculture, ii) gardens and parks; iii) sport fields; iv) industrial green spaces; v) roundabouts and roadsides green; vi) abandoned areas.

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As for **soil sampling** a consistent number of observations must then allocated in the different units in order to have a complete coverage of the different soil conditions within the urban fabric. The number of observations per mapping unit will be proportional to the area of the units (stratified random sampling) and will depend upon resources constrains. As a result, very small map units cannot be sampled. Accessibility to sampling sites must be verified in advance, as it is very likely that not all green areas would be granted access to the surveyors. The choice of sampling sites falls obviously on green spaces not occupied by buildings or roads such as public parks, medium-large private gardens, green sports fields, court areas belonging to schools, flowerbeds, roadsides and roundabouts, urban agricultural areas, woody ruderal sites, and abandoned areas. It is recommended to supplement each sampling site with a set of photographs that document: augering, soil cover, landfill (when present), views of the area with 4 perspectives (N, S, E. O) and a panoramic photo. The soil cores from augering are to be described following soil survey standards as those in the manual provided by the Soil Survey Service of Emilia-Romagna (http://ambiente.regione.emiliaromagna.it/it/geologia/temi/suoli/pubblicazioni-on-line-sul-suolo). The depth of the auger hole must reach 150 cm, unless obstacles are met (gravel, lithic or paralithic contact, extremely dry conditions). The collection of soil samples must differentiate the topsoil horizon(s) (0-30 cm) from the underlying subsoil horizons; the number of samples per sampling site will depend upon resources availability and the specific goals of the assessment (e.g. urban soils mapping, ecosystem services assessment).

The assessment of the ecosystem services provided by urban soils, either qualitative or quantitative relies on the availability of soil analytical data (Table 1. Soil parameter, analytical methods and references. *: required for soil ecosystem services indicator assessment.), both from field and from laboratory in order to derive indicators of ecosystem services provision (Blanchart et al., 2018). To this goal, a core set of laboratory analytical data is required encompassing at least: i) **soil texture** (at least three fractions, sand, silt and clay) and **coarse fragments** ($\emptyset > 2$ mm), ii) **soil organic carbon content**, and iii) **pH**. Depending upon resources availability and upon the goal of the assessment, additional soil routine analyses can address total nitrogen, calcium carbonates content, cation exchange capacity, exchangeable basis (Ca, Mg, Na and K), total base saturation, exchangeable Na percentage, and heavy metals concentration (**Errore. L'origine riferimento non è stata trovata.**). Among the listed parameters, **cation exchange capacity** is required for ecosystem service indicator assessment, but it can be estimated via PTF from clay and organic carbon content. All analyses must conform to the official standard analytical methods (e.g DM 13/09/1999, Approval of "Ufficial methods of soil chemical analyses").

Among the field analyses, it would be preferably to assess topsoil **bulk density** (by core sample method), and **saturated hydraulic conductivity** (e.g. by using a double head permeameter). These latter can also be estimated resorting to **pedotransfer functions (PTFs)** using as inputs soil textural fractions and organic carbon content. Similarly, water retention properties required for the assessment of soil ecosystem services, namely **air entry pressure** (cm), and **available water content** (AWC vol./vol., given by the difference between WC at field capacity, WC_{FC}, and water content at wilting point, WC_{WP}) can be assessed resorting to PTFs. To this aim, it is recommended to resort to locally calibrated PTFs whenever available (e.g. Ungaro et al. 2005; Ungaro et al., 2014)

As for soil biodiversity, the **Soil Biological Quality Index** is defined based on micro arthropods (**QBS-ar**, Parisi, 2001). These organisms present a complex series of adaptations to life in the edaphic environment, are sensitive to the state of suffering of a soil, and can be used as quality bio indicators.

Soil animals have different degrees of adaptation to hypogeal life, such as absence of visual organs, elongation and flattening of the body, shortening of sensory and locomotor appendices, reduction or disappearance of some appendages such as the furca (organ used for jumping) in the *Collembola* or the metathoracic wings in the *Coleoptera*, the presence of sensory organs to detect the degree of humidity, the depigmentation or the possible cryptic pigmentation to be confused with earth particles like in mites, the reduction or disappearance of sensory organs that absorb light radiations (Menta, 2012).



The various groups are defined by biological forms characterized by the same series of converging characters. These organisms have thus adapted themselves to the edaphic environment, and can no longer survive outside it (Parisi et al., 2005).

| Parameter | Unit | Method | Reference |
|--|--------------|--|--|
| Sand 2000-100µm | % | Sieve | D.M. 13/09/1999. Method II.5 |
| Sand 100- 50µm | % | Sieve | D.M. 13/09/1999. Method II.5 |
| Sand 2000-50 µm* | % | Sieve | |
| Silt 50-20µm | % | Pipette or hydrometer | D.M. 13/09/1999. Method II5, II.6 |
| Silt 20-2µm | % | Pipette or hydrometer | D.M. 13/09/1999. Method II5, II.6 |
| Silt 50-2 µm* | | Pipette or hydrometer | D.M. 13/09/1999. Method II5, II.6 |
| Clay <2µm* | % | Pipette or hydrometer | D.M. 13/09/1999. Method II5, II.6 |
| | | | |
| pH * | - | in H2O 1:2,5 | D.M. 13/09/1999. Method III.1 |
| Total CaCO3 | % | Gas volumetric | D.M. 13/09/1999. Method V.1 |
| Active CaCO3 | % | Droineau | D.M. 13/09/1999. Method V.2 |
| Organic C* | % | Elemental anlyzer | D.M. 13/09/1999. Method VII.1 |
| Total N | per thousand | Kjeldhal or Elemental anlyzer | D.M. 13/09/1999. Method XIV.3 o XIV.1 |
| CEC** | meq/100g | BaCl2 pH 8,1 for calcareous soils, NH4 acetate for acid soils | D.M. 13/09/1999. Method XIII.2, XIII.1 |
| | | | |
| Exchangeable Ca | meq/100g | BaCl2 pH 8,1 for calcareous soils, NH4 acetate for acid soils | D.M. 13/09/1999. Method XIII.5 XIII.4 |
| Exchangeable Mg | meq/100g | BaCl2 pH 8,1 for calcareous soils, NH4 acetate for acid soils | D.M. 13/09/1999. Method XIII.5 XIII.4 |
| Exchangeable K | meq/100g | BaCl2 pH 8,1 for calcareous soils, NH4 acetate for acid soils | D.M. 13/09/1999. Method XIII.5 XIII.4 |
| Exchangeable Na | meq/100g | BaCl2 pH 8,1 for calcareous soils, NH4 acetate for acid soils | D.M. 13/09/1999. Method XIII.5 XIII.4 |
| TBS total base saturation | - | Derived parameter = exchangeable basis/CEC *100 | |
| ESP Exchangeable Na percentage | - | Derived parameter = exchangeable Na /CSC *100 | |
| | | | |
| Heavy metals (As, Cd, Cr, Cu, Ni, Pb, Sb, Sn, V, Zn) | mg/kg | Extraction in <i>aqua regia</i> + ICP-MS | UNI-EN 13346:2002 / EPA 6020 EPA 3051A 2007 /EPA 6020 EPA 3051A 2007 /EPA 6010 UNI EN 16174:2012 B+UNI EN 16171:2016 |

 Table 1. Soil parameter, analytical methods and references. *: required for soil ecosystem services indicator assessment.

 **: required for soil ecosystem services indicator assessment but derivable via PTFs.

Sampling for QBS-ar must take into account the information on land use, the data on the averages of rainfall preceding the tiem of sampling, and the soil humidity at the time of sampling. At each sampling site, three replicas are taken consisting of distinct cubic clods of 10 cm on each side, collected at points 5 to 10 meters apart, trying to encompass as much as possible the observed field variability. After removing any litter or herbaceous cover, the samples are placed in plastic bags in which a reserve of air must remain.

The **description of soil profiles** is required only for urban soils mapping purposes, as their field description and analysis can provide the information necessary to highlight the relationship between *in situ* soil materials and exogenous material, either soil or of anthropic nature. In this way, it become possible to assess the actual nature, degree and extent of soil disturbance due to different anthropic activities and how this is likely to affect the provision of ecosystem services. The number of soil profiles (that can be excavated or be observed along already open ditches) will depend upon the number and the area of the mapping units identified and from the analytical data from auger-holes samples. Furthermore, data from soil profile will

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support the definition of **urban soil mapping units**; soils are classified according to WRB (IUSS - Working Group WRB, 2014), which is more suitable and versatile of Soil Taxonomy (Soil Survey Staff, 2014) in the classification of urban soils.

Also useful to the aim of characterizing and mapping urban soil is the assessment of the **degree of soil sealing** of each mapping unit. The assessment can be based either on technical documentation at municipality scale if available, or resorting to the last update (2018) of the CORINE land cover map (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download) or, even better, to the soil sealing map yearly updated by ISPRA at a 10 m resolution (http://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/consumo-di-suolo/carta-nazionale-consumo-suolo).

The soil mapping units in the final urban soil map will then result from a refinement of the preliminary urban pedolandscapes units based on the evidences stemming from analytical results and soil profiles description, eventually supported by the available information on land use/land cover, degree of soil sealing, digital elevation model, and multi-temporal aerial photos series.

2.1.2 Using existing soil information: examples for Emilia Romagna region and Italy

In case an ad hoc survey is not possible, ESs can be assessed at general scale using existing soil and ancillary information. The needed minimum information is reported in table 3.

| MADS | NECESSADV2 | NOTES |
|--|------------|---|
| MAP3 | NECESSART | NOTES |
| Detailed or semi-detailed soil map (scale 1:25.000-1:50.000) | Y | |
| Detailed or semi-detailed Land Capability map (scale 1:25.000- | | |
| 1.50,000) | Y | |
| Detailed or somi detailed land use man (scale 1:25 000 1:50 000) | V | |
| Detailed of serifi-detailed fand use map (scale 1.25.000-1.50.000) | I | CORINE LAND COVER 4 level |
| Benchmark soil profiles, with analyses for texture, organic carbon | NO | Only in case the following maps are not available |
| content, CEC. | | only in case the following maps are not available |
| | | |
| Map of texture and coarse fragments content of topsoil | Y | Either mana of the first 100 cm |
| | | Entier maps of the first 100 cm. |
| Map of texture and coarse fragments content of subsoil | Y | |
| Map of organic carbon content in topsoil | Y | |
| Mon of organic carbon content in subscil | v | Either maps of the first 100 cm. |
| Map of organic carbon content in subsoli | Ť | |
| Map of organic carbon stock in topsoil | NO* | Either mana of the first 100 cm |
| Map of organic carbon stock in subsoil | NO* | Entrer maps of the first 100 cm. |
| Map of organic carbon stock in topsoil Map of organic carbon stock in subsoil | NO* NO* | Either maps of the first 100 cm. |

Table 2. Information layers for ESs assessment. Soil organic carbon stock can be calculated from SOC and bulk density (calculated via PTF)

Many Italian Regions¹ hold this information, e.g. Emilia-Romagna², Veneto³, Piemonte⁴, Lombardia⁵, Toscana⁶, Campania⁷. Some Regions, as Basilicata⁸ and Calabria⁹, hold this information only at general scale (1:250,000).

As for Carbon stock, the recently produced Global Soil Organic Carbon Stock map (FAO, 2017) is available at http://54.229.242.119/GSOCmap/.

¹ http://ambiente.regione.emilia-romagna.it/it/geologia/temi/suoli/il-suolo-nel-web-siti-delle-regioni-italiane

² <u>http://ambiente.regione.emilia-romagna.it/it/geologia/temi/suoli/cartografie</u>

³ <u>http://geomap.arpa.veneto.it/people/profile/suoli/?limit=100&offset=0</u>

⁴ http://www.sistemapiemonte.it/cms/privati/agricoltura/servizi/383-carta-dei-suoli-1-50-000

⁵ <u>https://www.dati.lombardia.it/browse?q=basi%20informative%20suoli&sortBy=relevance</u>

⁶ http://www502.regione.toscana.it/geoscopio/pedologia.html

⁷ http://www.agricoltura.regione.campania.it/pedologia/suoli.html

⁸ http://www.basilicatanet.it/suoli/derivate.htm; http://www.basilicatanet.it/suoli/comuni.htm

⁹ <u>http://www.arsacweb.it/pubblicazione/le-novita-della-pac-per-il-2015-e-gli-obblighi-di-condizionalita-per-le-aziende-agricole/</u>



Using locally calibrated **pedotransfer functions** (PTFs) the following data required for the assessment can be calculated:

- bulk density (Mg m⁻³),
- saturated hydraulic conductivity (mmh⁻¹),
- air entry pressure (cm),
- available water capacity (vol./vol.), derived from the estimated water content at 333 and 1500 cm tension,
- cation exchange capacity (cmol_c kg⁻¹)

2.1.3 Tutorial for consulting websites of Emilia-Romagna Region.

All the cited information layers are available for Emilia-Romagna region. This tutorial aims at guiding users in retrieving the available soil data on regional portals.

DGCTA minERva portal (in Italian) aims at divulging and distributing all the information and data produced and owned by DG Land and Environment Care to the wide public and to the staff of local and national public administrations. Through the portal, it is possible to access all the regional thematic and applicative maps, including soil maps.

Access to the web portal is through the following URL:: <u>https://datacatalog.regione.emilia-romagna.it/catalogCTA/</u>

| R DG CTA | og.regione. emilia-romagna.it /ca | stalogCTA/ Dataset | ,О + Gruppi Geo | Benver | nuti - Catalogo CTA Informazioni | × Catalogo dei tip | si di suolo Q |
|----------|--|---|---|--|---|--|---|
| | Cerca i dati + CUNEO ALDES- | LESSANDRIA | REGGIO | D FERRA Bologna RAVI | RA | 0 | HRV-99 CROATIA MINOR ISLAND) |
| | Per es. ambiente | TA rappresenta il j erritorio ed Ambier ntegrare le informa gge Regionale n. 2 no organizzate in d Service | punto di riferime nte della Region azioni necessari 14 del 2017 – Dis lataset e posson " (WFS), vettoria | ento e di condi e Emilia-Roma, e per la predis, ciplina regiona to essere fruibi Il SHAPEFILE d | visione delle info gna. Uno degli o posizione dei qu ale sulla tutela e ili tramite "Web i o in formato tabo | ormazioni detenute biettivi del portale adri conoscitivi di l'uso del territorio. Map Service" (WM: ellare. | Q dalla Direzione è quello di fornire cui all'art.22 della S), "Web Feature |
| | l dati cartogr Il portale è real | Service Service afici possono esse izzato in tecnologi source e basato su | " (WFS), vettoria ere consultati att a Comprehensiv I web per la racc | li SHAPEFILE traverso un vis ve Knowledge J colta, la catalog | o in formato tab ualizzatore carto Archive Network gazione e la disti | ellare. ografico, il GeoViev (CKAN) che è un s ribuzione di dati. | vER Moka. sistema open |

Figure 2. Portal minERva: homepage interface



In the homepage (Figure 2), the menu in upper bar allows to access and navigate the contents of the portal. Selecting the menu "**Gruppi**" the user has access to 33 different catalogs (<u>https://datacatalog.regione.emilia-romagna.it/catalogCTA/group</u>); on the second page the group "**Suolo**" is available to access soil related data and maps (Figure 3).

At the page "**Suolo**", 14 datasets/maps are available (Figure 4); these are available in different formats (HTML, WMS, KML, ESRI), but they all refer to the same page where all the formats made available to the user are listed (in Figure 5, the example for topsoil texture is reported).





| / Gruppi / Suolo | |
|-----------------------------|--|
| <u></u> | A Dataset O Flusso di attività Informazioni |
| | Cerca dataset Q |
| Suolo | 14 dataset trovati Ordina per: Rilevanza |
| Sostenitori Dataset 0 14 | <u>Carta del Fondo Naturale a scala 1:250.000 della pianura emiliano-romagnola - Cr, Cu, Ni, Pb, V, Zn</u> |
| T Gruppi | Rappresenta la distribuzione areale nel subsoil (90-140 cm di profondità) del contenuto di 6 metalli (Cr, Cu Ni, Pb, V, Zn) nei suoli ad uso agricolo. Tale profondità è |
| Suolo (14) | KMZ HTML WMS html_simpl |
| ▼ Tag | Carta del Fondo naturale-antropico della Pianura emiliano-romagnola, scala 1:250.000 |
| Suolo (14) | La "Carta del contenuto di Fondo naturale-antropico" rappresenta la distribuzione areale nel topsoil (20-30 |
| Stock Carbonio (4) | cm di profondità) di alcuni metalli potenzialmente tossici [As, Cr, |
| Pianificazione Agri (4) | KMZ HTML WMS |
| Gas-A-Effetto-Serra (4) | Carta dei suoli – Pianura, basso e medio Appennino emiliano-romagnolo, scala |
| Carbonio Organico (4) | 1:50.000 - Edizione 2018 |
| Proprietà Chimiche (3) | Descrive i suoli e la loro distribuzione geografica nella pianura, in gran parte (93%) del basso Appennino (collina) e una piccola parte (10%) del medio Appennino della regione |
| Fertilità Del Suolo (3) | WMS HTML Esri Shape |
| Ambiente (3) | |
| Salinità Del Suolo (2) | Carta dei Gruppi Idrologici della pianura emiliano-romagnola |
| Protezione Delle Acque (2) | La carta deserve la distribuzione areale dei Gruppi ratiologici dei Subii attraverso i poligoni della Carta dei Suoli di pianura in scala 1:50.000. Ogni poligono è descritto |
| Mostra altro Tag | WMS Esri Shape HTML |
| ▼ Formati | Salinità dei suoli della pianura emiliano-romagnola tra 0-50 cm |
| Wms (14) | La carta della salinità descrive lo stato di salinità dei suoli tra 0-50 cm. E' una rappresentazione derivata d |
| Html (14) | WMS Esri Shape HTML |
| Shp (12) | |
| Kmz (2) | Salinità dei suoli della pianura emiliano-romagnola tra 50-100 cm |
| Html_Simpl (1) | La carta della salinità descrive lo stato di salinità dei suoli tra 50-100 cm. E' una prima rappresentazione derivata da analisi geostatistica a partire da dati puntuali |
| | WMS Esri Shape HTML |

Figure 4. Partial list of the SOIL available datasets



Figure 5. Retrieving regional data: example for topsoil texture

There are several options for accessing data:

- first option allows visualising the layer in Moka viewer (preview) and downloading in WMS format
- second option allows downloading as shapefile
- third option allows visualising the layer on a web-gis, "**Cartografia dei suoli**", together with other thematic maps. On this site it is possible to download the description of the 1:50,000 soil map polygons and the analyses of the reference soil profile.
- Fourth option allows visualising the layer on the web-gis "I suoli dell'Emilia-Romagna" (CARTPEDO), in GOOGLE EARTH environment.
- Fifth option re-address to the webpages of the Soil Survey Service of Regione Emilia-Romagna.

The 1:50,000 soil map (2018) is available in vectoral format for 71% of the regional territory (plain areas, hills and low mountains). Land capability map (2010) is available for plain areas only. Maps of texture, organic carbon content (%) and stock (Mg ha⁻¹) are available for topsoil,I (0-30 cm) and subsoil (30-100 cm), and are referred to a 500 x 500 m grid in plain areas. Soil organic carbon and stock are available also for hills and mountains in a 1000x1000 m grid.



2.2 Soil ecosystem services assessment

The methods for calculating the indicators is described in the project deliverable (Action B1.2) "*Misurazione a scala comunale degli impatti del consumo dei suoli e valutazione dei servizi ecosistemici*" (in Italian), and in the article "*A methodological framework to assess the multiple contributions of soils to ecosystem services delivery at regional scale*" (Calzolari et al., 2106), both available at the SOS4LIFE website (http://www.sos4life.it/documenti/). The considered ecosystem services, the underpinning soil functions and the input data required for their assessment are summarized in Table 3. Ecosystem services (ESs), underpinning soil functions, indicators and input data. ^{aMEA} 2005; ^{bDominati} et al. 2010; ^{cEuropean} Commission (EC), 2006.

| ESs categoriesª | Soil contribution to ESs ^b | Soil function ^c | Indicator | Input data | Code |
|------------------------------|---|---|--|--|------|
| Supporting | Habitat for soil organisms | Biodiversity pool | Potential habitat for soil organisms | Land use Bulk density Organic C | BIO |
| Regulation | Nutrient and pollutants retention and release; Natural attenuation (potential) | Storing filtering and transforming nutrient, substances and water | Cation exchange capacity Soil reaction Rooting depth | Organic C Clay content pH (0-30) Average shallow groundwater depth | BUF |
| Regulation | Microclimate regulation (potential) | Storing filtering and transforming nutrient, substances and water | Soil evaporation potential | Available water capacity Average shallow groundwater depth | CLI |
| Regulation | Carbon sequestration (potential) | Carbon pool | Carbon sequestration actual | Organic C and bulk density (0-30 cm) | CST |
| Provisioning | Food provision (potential) | Biomass production | Land capability (LC) map | LC classes and intergrades | PRO |
| Regulation | Water regulation /Runoff -flood control (potential) | Storing filtering and transforming nutrient, substances and water | Infiltration capacity | Hydraulic saturated conductivity Air entry point | WAR |
| Regulation (Provisioning) | Water regulation - Water storage (potential) | Storing filtering and transforming nutrient, substances and water | Water content at field capacity Presence of water table | Field Capacity (-33 kPa) Average shallow groundwater depth | WAS |

Table 3. Ecosystem services (ESs), underpinning soil functions, indicators and input data. ^aMEA 2005; ^bDominati et al. 2010; ^cEuropean Commission (EC), 2006.

The calculation results for each indicator are standardised as numbers in the range 0 to 1 (Wu et al., 2013) resorting to an interval normalization as follows:

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

where $X_{i\ 0-1}$ is the standardised [0-1] value, X_i is the actual value, X_{min} and X_{max} are the minimum and the maximum respectively of each considered variable in the dataset. The formula gives values close to 1 to higher values of the considered input variable or indicator; the lowest value, 0, does not indicate that the input variable value is equal to 0 or that the function is not provided, but that it is the lowest in the considered area. It is of pivotal importance then to tailor the assessment to the scale of investigation and to the goal of

the analyses, as results will be deeply affected by the degree of variability observed in soil measured and estimated soil properties, whose ranges are strongly scale dependent and different for each variable. The calculation procedures for each indicator are summarized in Table 4. Calculation procedures for the selected indicators of soil based ecosystem services.

| Code | Input data | | | | | C | Calcula | ation | | | | |
|------|--|---|---|--|--------------------------------------|-----------------------------|--------------------------------|------------------------------------|---------------------------|---------------------------|---------------------------------|---------------------------------------|
| BIO | QBS _{ar} as a function of dominant Land use (High= 1; Medium= 0.5; Low= 0.25) Bulk density, BD (mg ha ⁻¹) Organic C, OC (%) | $BIO_{0-1} = (LogOC_{0-1} - BD_{0-1}) + QBS_{ar \ 0-1}$ | | | | | | | | | | |
| BUF | CSC (cmolc/kg) as a function of Organic C (%) and clay content (%) CEC = 6.332 +0.404 Clay + 1.690 OC (R ² = 0.75) pH Average shallow groundwater depth, WT (cm) | $\begin{split} BUF_{0-1} &= Log\ CSC\ (pH;\ sk)_{0-1} \\ \textit{with } pH{<}6.5\ \textit{reduction } \textit{by } 0.25\ \textit{or } 0.5\ \textit{depending }\textit{on } \mathit{CSC}\ \textit{and } \textit{skel}{>}30 \\ \textit{by } 0.25 \\ & for water table \ deeper \ than \ 100\ cm, \ and \\ BUF_{0-1} &= Log\ CSC\ (pH;\ sk)_{0-1}^*WT/100 \\ & \text{in case of occurrence of a shallow water table within the first \ 100\ cm \\ & \text{soil depth, being WT the average water table depth (cm).} \end{split}$ | | | | | | e <i>l>30%</i> 0 cm of | | | | |
| CLI | Available water capacity, AWC (vol/vol) AWC= WC _{FC} -WC _{WP} Average shallow groundwater depth, WT (cm) | | | | (| CLI ₀₋₁ | = logA | WC ₀₋₁ + | WT ₀₋ | 1 | | |
| CST | Organic C, OC (%) Bulk Density, BD (Mg m ⁻³) | | | | С | ST ₀₋₁ | = log (| OC * BD |) ₀₋₁ | | | |
| PRO | LC classes and intergrades | LCC Score LCC Score | I 1 III/IV 0.5 | I/II0.95III/VI0.3 | II 0.8 IV 0.4 | II/I 0.9 IV/II 0.5 | II/III 0.7 IV/III 0.5 | II/III/IV 0.65 IV/VI 0.27 | II/IV 0.55 V 0.3 | III 0.6 V/II 0.4 | III/II 0.65 VI/IV 0.25 | Ⅲ/Ⅲ/Ⅳ 0.57 Ⅶ 0 |
| WAR | Hydraulic saturated conductivity, Ksat (mmh ⁻¹) Air entry point , PSIe (cm) | 00010 | | | | WAR | $k_{0-1} = 10$ | ogKsat₀₋ | ₁−PSI€ | ∂ 0−1 | | |
| WAS | Field Capacity (-33 kPa), WC _{FC} (vol/vol) Average shallow groundwater depth, WT (cm) Sk, coarse fragments (Ø >2 mm, vol/vol) | WA WAS ₀ | AS _{0−1} = _{−1} = (W | : (WC _F /C _{FC} * | c * 1 1-sk) | −sk) _{0–} *WT/1 | ₁ for w 00 for | ater tabl water ta | e deep ble wit | er tha hin th | an 100 e first í | cm, and 100 cm |

Table 4. Calculation procedures for the selected indicators of soil based ecosystem services.

As for **BIO**, we defined three qualitative classes for QBSar based on data from literature (Menta et al., 2008) and depending upon dominant land use: High (QBS-ar, 150-250) for permanent meadows and pastures, woodlands, and peatlands; Medium (QBSar, 100-150) for agricultural lands under rotation with meadows and minimum tillage; and Low (QBSar, 60-100) for other land uses. QBS-ar in sealed or strongly anthropized is equal to 0 (Prokop et al, 2011).

For the assessment of **PRO** we used as a proxy of agricultural production the **Land Capability Classification** class and intergrades, transforming the original ordinal scale into a continuous one with a score ranging from 1 to 0 (Table 4). The LCC was originally developed by the Soil Conservation Service of the U.S. Department of Agriculture (Klingebiel and Montgomery, 1961), and adapted to local soil conditions (Guermandi, 2000). The LCC map is available at the scale 1:50,000 (Regione Emilia Romagna, 2010) for the plain areas (https://geo.regione.emilia-romagna.it/cartpedo/carte_tematiche.jsp?tem=2#tem2).

For the assessment of the **BUF**, **CLI** and **WAS** indicator, the presence of a **shallow water table** within 100 cm depth is taken into account. Floodplain soils depth is always greater than 100 cm, but the presence of a shallow water table can locally reduce the rooting depth; in this case the depth of shallow water table in the first 100 cm of soil was taken into account for decreasing the overall attenuation and storage capacity of the soil. This information was derived by the long term average depth of the shallow water table map (Figure 6) available for the plains of Emilia Romagna (Barca et al., 2014; Calzolari and Ungaro, 2012).





Figure 6. Long-term average depth of the shallow water table.

Assuming that the soils sealed by urbanisation are not capable to provide any ecosystem service, as they lost their multi-functionality, we suggest to use the yearly updated map of soil sealing provided by ISPRA at a 10 m resolution () to weigh the indicators values. For example, adopting a regular grid with cell size depending on the scale of investigation, the relative fraction (range 0-1) occupied by built areas (URB) is considered and used to rescale each indicator as follows:

Indicator_final = Indicator*URB₀₋₁

3. MANAGING

As discussed, urban soils provide important ecosystem services that can be of high quality. They also may provide disservices, mostly linked to pollution risk and the associated impacts on human health. Soil survey and soil functions and ecosystem services assessment provide urban planners with a tool for an aware approach to planning, taking into consideration the role of soil in the urban environment. Moreover, the assessment of the services provided by soil and of their overall quality should lead the urban planner choices as regard policies of densification. Even if urban densification may represent an alternative to urban sprawl, the best performing soils should be protected.

Whatever the planning choices, urban green areas should be managed in a sustainable way (FAO, 2017), which in an urban environment means reducing at most the hamper for soil functioning.

The following constitutes general, and not exhaustive, guidelines to address major soil threats in urban areas.

Enhance soil organic matter content

Soil organic matter plays a central role in maintaining soil functions and preventing soil degradation. Moreover, urban soils may stock organic carbon contributing in reducing CO₂ emissions.

- In parks and garden: increasing biomass production (by increasing water availability for plants using methods that maximize water-use efficiency and minimize soil erosion and nutrient leaching, balancing fertilizer applications and green manures); implementing urban forestry; managing crop residues, minimising their removal,
- ii) In flowerbeds: Increasing organic matter using organic amendments, compost, and applying mulches or providing the soil with a permanent cover;
- iii) In roadside green: using cover vegetation resistant to trampling.
- iv) In agricultural allotments (urban vegetable gardens, residual agricultural fields), support management practices such as cover crops, reduced- or no-tillage practices, organic fertilisation.

Prevent and minimize soil contamination

Soil may filter, fix and neutralize, but also release pollutants, especially in urban areas. Therefore, prevention of soil contamination remains the best way to maintain healthy soils and human health. Monitoring pollution sources and potentially polluted soils will help in applying prevention policies and regeneration strategies.

Preserve and enhance soil biodiversity

Soils provide large reservoirs of biodiversity, and soil organisms underpin most of the soil based ecosystem services. Due to the presence of a wide variety of microhabitats with different features evolving with time, urban soils may provide a high level of biodiversity. As urban soil biodiversity is strongly influenced by the degree of disturbance, management can help in preserving and enhancing it.

- i) In all green areas: restoring plant biodiversity, thereby favouring soil biodiversity
- ii) In parks and gardens: using nitrogen fixing leguminous species.
- iii) In all green areas: adopting soil organic matter enhancing management practices
- iv) In agricultural allotments: crop rotation, inter-cropping, and preservation of field margins, hedges and biodiversity refuges;
- v) Reducing the use of pesticides.



Prevent and mitigate soil compaction

Soil compaction is related to the degradation of soil structure and results in an increase in soil bulk density. Soil compaction reduces soil aeration, water drainage and infiltration, generating higher runoff. In urban areas, the main drivers of compaction are the stresses imposed by heavy machinery in construction sites and by people trampling in parks/gardens.

For mitigating the disturbance due to heavy machinery in construction sites some guidelines are included in the document "Guidelines for the removal, management and re-use of topsoil at construction sites" that can be retrieved at the following address: <u>http://www.sos4life.it/documenti/</u>. In the same document, some guidelines are reported for the re-use of topsoil in new green areas.

All the measures useful for preserve and enhance soil organic matter content and biodiversity have also positive impacts on preventing soil compaction.

Table 5. *Relationship between soil bulk density and root growth based on soil texture (NRCS Soil Quality Institute, 1999)*. shows reference soil bulk density values for different soil textural classes, and their relationships with root growth (NRCS Soil Quality Institute, 1999).

| Soil texture | ldeal bulk densities (g/cm3) | Bulk densities that may affect root growth (g/cm3) | Bulk densities that restrict root growth (g/ cm3) |
|---|------------------------------------|--|---|
| Sands, loamy sands | <1.60 | 1.69 | >1.80 |
| Sandy loams, loams | <1.40 | 1.63 | >1.80 |
| Sandy clay loams, loams, clay loams | <1.40 | 1.6 | >1.75 |
| Silts, silt loams | <1.30 | 1.6 | >1.75 |
| Silt loams, silty clay loams | <1.10 | 1.55 | >1.65 |
| Sandy clays, silty clays, some clay loams (35-45% clay) | <1.10 | 1.49 | >1.58 |
| Clays (>45% clay) | <1.10 | 1.39 | >1.47 |

Table 5. Relationship between soil bulk density and root growth based on soil texture (NRCS Soil Quality Institute, 1999).

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ANNEX I. PEDOTRANSFER FUNCTIONS

We describe here a set of pedotransfer functions (PTFs) that can be used to estimate the data required for the assessment of the indicators of soil ecosystem services:

- bulk density (Mg m⁻³)
- saturated hydraulic conductivity (mmh⁻¹)
- air entry pressure (cm)
- available water capacity (vol./vol.), derivato dal contenuto d'acqua stimato a 333 e 15000 cm di tensione
- cation exchange capacity (cmol_c kg⁻¹)

A I.I Bulk density

Soil bulk density is required either as direct input for the calculation of indicators (e.g. soil organic carbon stock, infrastructure support capacity) or as input for the estimation of variables which are in turn required for the calculation of indicators, such as, for example, saturated water conductivity or air entry pressure required to estimate the indicators of water flow regulation in soils.



Figure 1. Italian soil regions.

Scientific literature provides a number of PTFs to estimate bulk density. These are calibrated on databases that can be local, regional or continental. In Italy, for examples, PTFs calibrated at regional level are available for Emilia Romagna (Tarocco et al. 2018), Tuscany, and Veneto. More recently, it has been established a database at national level of soil bulk density data (N = 3043) to support the realization of the first soil carbon stock map (0-30 cm) of Italian soils. To this goal, PTYFs have been calibrated for major land uses (woodlands, pastures and meadows, permanent crops, annual crops) in each of the ten Italian soil regions (Fig. 7), as defined by the Council for Agricultural Research and Economics (CREA-AA). A specific PTF for



organic soil horizon has been calibrated as well. The inputs required to estimate bulk density are soil textural fractions (sand, silt, clay, USDA limits) and soil organic carbon %. Particle mean diameter Dg (mm) and its standard deviation (Sg -) are computed from the three particle size fractions % as follows (Shirazi et al, 1988):

$$Dg = exp(a), Sg = exp(b)$$

where

$$a = \sum_{i=1}^{n} f_i \ln(M_i)$$
 $\mathbf{e} \quad b = \sqrt{\sum_{i=1}^{n} f_i (\ln(M_i))^2 - a^2}$

with n the number of textural fractions, f_i the amount of fraction i^a , and M_i the logarithmic mean of the limit values of the corresponding dimensional range.

The following tables report the algorithms to estimate soil bulk density for the four major land uses in the different Italina soil regions. General linear models (GLM) were used to calibrate the PTFs using the soil regions as cathegorical predictors.

| Soil Region | Intercept | C org | Clay | Dg | Sg | Soil Region | |
|-------------|------------|-------------|---------------|----|-------------|-----------------------|--|
| Tutte | 1.46823303 | -0.07045189 | -0.0006427181 | | -0.00217045 | A -0.072846634 | |
| | | | | | | B 0.084066381 | |
| | | | | | | C 0.032496028 | |
| | | | | | | D 0.125400466 | |
| | | | | | | E 0.143919304 | |
| | | | | | | F -0.141780125 | |
| | | | | | | G -0.018292945 | |
| | | | | | | H -0.175243435 | |
| | | | | | | I -0.098264484 | |
| | | | | | | L 0.120545443 | |
| | | | | | | | |

Table 1. GLM PTF for bulk density estimation (Mgha-1): annual crops.

| Soil Region | Intercept | C org | Ln C org | Clay | Silt | Sand | Dg | Sg | Soil Region |
|-------------|------------|-------------|----------|------|-----------|------|----|----|-----------------------|
| Tutte | 1.44443065 | -0.07618995 | | | 0.0004791 | | | | A 0.0912244411 |
| | | | | | | | | | B 0.0305390199 |
| | | | | | | | | | C 0.105238663 |
| | | | | | | | | | D 0.141192449 |
| | | | | | | | | | E 0.0601010732 |
| | | | | | | | | | F -0.110013133 |
| | | | | | | | | | G -0.05491585 |
| | | | | | | | | | H -0.192832061 |
| | | | | | | | | | I -0.161653454 |
| | | | | | | | | | L 0.091118852 |

Table 2. GLM PTF for bulk density estimation (Mgha-1): permanent crops.

| Soil Region | Intercept | C org | Ln C org | Clay | Silt | Sand | Dg | Sg | Soil Region |
|-------------|-----------|------------|----------|------|------------|------|----|-----------|------------------------|
| Tutte | 1.2918347 | -0.0649351 | | | 0.00231335 | | | 0.0007366 | A -0.1269407950 |
| | | | | | | | | | B 0.0018918827 |
| | | | | | | | | | C 0.1213344180 |
| | | | | | | | | | D 0.1492775290 |
| | | | | | | | | | E 0.0356893461 |
| | | | | | | | | | F -0.3179206830 |
| | | | | | | | | | G 0.0396237258 |
| | | | | | | | | | H 0.0364853163 |
| | | | | | | | | | I -0.073262287 |
| | | | | | | | | | L 0.133821547 |
| | | | | | | | | | |

Table 8. GLM PTF for bulk density estimation (Mgha-1): permanent meadows and grasslands.

| Soil Region | Intercept | C org | Ln C org | Clay | Silt | Sand | Dg | Sg | Soil Region |
|-------------|-----------|-------|----------|------|------|------|----|----------|-----------------------|
| Tutte | 1.216743 | | -0.16795 | | | | | 0.006818 | A -0.263105989 |
| | | | | | | | | | B -0.005306609 |
| | | | | | | | | | C |
| | | | | | | | | | D 0.0206395292 |
| | | | | | | | | | E 0.0271433492 |
| | | | | | | | | | F -0.0224236601 |
| | | | | | | | | | G -0.056813692 |
| | | | | | | | | | H 0.1663454444 |
| | | | | | | | | | I 0.1501642310 |
| | | | | | | | | | L -0.0166426618 |
| | | | | | | | | | |

Table 9. GLM PTF for bulk density estimation (Mgha-1): woodlands.

As for organic soil horizons, regardless of land use and soil region, the general relationship between soil organic carbon content and bulk density is the following:

Bulk density (Mg m⁻³) = 1.40275788 - 0.338701096*LN (C org. %)

Correcting soil bulk density for coarse fragments content

The presence of coarse fragments (diameter > 2mm) often characterize urban soils and, for this reason, it is necessary to correct the PTF estimates of bulk density. The corrected BD values in presence of coarse fragments can be calculated from the BD values fo fine earth and corse fragments (Berger, 1976). In order to calculate the bulk density of the whole soil BDt, i.e. encompassing fine earth and coarse fragments, we adopt the following equation:

$$BD_{t} = [(1-R_{m})/BD_{f} + (R_{v}/BD_{rf})]_{-1}$$
(1)

where R_m is the coarse fragments content on a weigth basis; BDt is the total bulk density (Mg m⁻³), BD_{rf} is the bulk density of the coarse fragments (reference values are available in literature for different litologies;



for example the mean value for the soils of Emilia-Romagna is 2.26 Mg m⁻³), and BD_f is the bulk density of the fin earth fraction (estimated via PTF).

Generally the available data for coarse fragments in on a volume basis (R_v). The transformation from a volume based to a weight based content is obtained with the following (Torri et al, 1994):

 $R_m = (-BD_{rf} R_v) / (BD_f R_v - BD_{rf} R_v - BD_f) (2)$

In order to account for the effect of coarse fragments on the bulk density of the fine earth, resulting in an inverse relationship due to the presence of voids and macropores at the interface between coarse fragments and fine earth, it is necessary to resort to the following (Torri et al., 1994):

$$BD_{f_c} = BD_{f_c}(1 - 1.67R_{m^{3.39}})$$
 (3)

where BD_{f_c} is the fine earth bulk density in presence of coarse fragments (Mg m⁻³); BD_f, is again the bulk density of the fine earth estimated via PTF without accounting for the presence of coarse fragments; R_m is the coarse fragments content on a weight basis.

Equation (1) can be written as follows:

$$BD_{t} = [(1-(-BD_{rf}R_{v}) / (BD_{f}R_{v} - BD_{rf}R_{v} - BD_{f}))/ (BD_{f}(1 - 1.67R_{m^{3.39}})) + (R_{v}/BD_{rf})]_{-1}$$
(4)

Equation (4) is generally used to correct PTF bulk density estimates in soils with more than 10% of coarse fragments.

As for Emilia-Romagna soils, a map of bulk density estimates is available as additional data to the carbon stock map for the plain area of the region, for the interval depth 0-30 cm¹⁰.

¹⁰ http://mappegis.regione.emilia-romagna.it/gstatico/documenti/dati_pedol/NOTE_ILLUSTRATIVE_stockCO30_pianura.pdf

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Figure 2. Example of query of the C stock map on the CARTPEDO webpage.



A I.II Saturated hydraulic conductivity

Soil literature provides a number of PTFs to estimate hydraulic conductivity. Among these, one of the most used, and validated with fair accuracy ($R^2 = 0.35$) on an independent dataset for Italian soils (N = 268), is the PTF proposed by Brakensiek et al. (1984):

Ksat (mm h⁻¹) = 10* EXP [(19.52348*PORO2) - (8.96847) - (0.028212*A%) + (0.00018107*S%^2) - (0.0094125* A%^2) - (8.395215* PORO2^2) + (0.077718* S%* PORO2) - (0.00298* S%^2* PORO2^2) - (0.019492* A%^2* PORO2^2) + (0.0000173* S%^2* A%) + (0.02733* A%^2* PORO2) + (0.001434* S%^2*PORO2) - (0.0000035* A%^2* S%)]

where the inputs to the PTF are: sand % (S%), clay % (A%), and porosity (PORO, vol/vol) as estimated from bulk denisty BD (Mg m^{-3}):

PORO=(1-BD/2.65)

On the same dataset of measurements Ungaro et al. (2014) calibrated a PTF resorting to GMDH (Group Method of Data Handling) statistical networks (Ivakhnenko, 1968). The calibrated network has the following sructure:



PTF inputs are sand (S%), clay (A%), organic carbon content (CO%) and bulk density (BD, Mg m⁻³, measured or estimated via PTF, and corrected for coarse fragments). Input variables are normalized prior to being transferred though the network nodes, using the following algorhythms:

Normalization input 1

A = -1.58807939026797+ 0.043399261792585 * S% B = 0.895704956226224+ 1.90436429623194 * log(CO%) C = -6.56853764508901+ 4.86964821073382 * BD

Output first node of the network

```
D = 0.0836015967122676+ 0.416153421876942*A + 0*B + -0.445772230372808*C + -
0.134334562427775* A^2 + -0.0544032825090131*B^2 + 0*C^2 + -0.198584356240143*A*B +
0.096017083549925*A*C + -0.125314845712128*
```

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A*B*C + 0.0716205065345566*A^3 + -0.123673920290893*B^3 + 0.0587033757513834*C^3 + 0.152071065904968*A^2*B+ -0.102414907323155* A*B^2+ 0*A*C^2+ 0* A^2*C+ - 0.156148957009503*B^2*C+ -0.0305947339564729*B*C^2

Normalization input 2

E= -1.65784483580252+ 0.0723996897397788* A%

Output second node of the network

F = 0.174732633027132+ 1.03829358346795***D** + 0.151865200913679***E** + -0.341867233805586***D**^2 + -0.11074767165566***E**^2 + -0.13351716106058***D*****E** + -0.461153694809156***D**^3 + 0***E**^3 + -0.367403924274197***D**^2***E** + -0.218709934220076***D*****E** ^2

Final output

Log Ksat= 0.951757462686567+ 1.10472133391165* F

Output check

Valiudity ranges for estimates are defined as follows:

| Range output | Ksat mm/h min | Ksat mm/h max |
|-----------------------|------------------|------------------|
| Fine textured soils | 0.0044 | 24.34 |
| Loamy textured soils | 0.93 | 100.93 |
| Coarse textured soils | 7.54 | 401.79 |

In case of Ksat estimates falling outside the limit of the calibration range, it is advisable to resort to mean values for USDA textural classes as reported in the following table.

| Textural Classes | Mean | Std.Dev. | 95% Cl lower | 95% Cl upper | Min. | Median | Max. |
|------------------|--------|----------|-----------------|-----------------|--------|--------|--------|
| С | 1.47 | 2.07 | 0.04 | 7.51 | 0.00 | 0.78 | 24.34 |
| CL | 11.62 | 7.85 | 2.81 | 32.30 | 0.93 | 9.53 | 75.13 |
| L | 12.57 | 2.61 | 8.31 | 18.34 | 6.80 | 12.33 | 25.28 |
| LS | 41.87 | 19.40 | 14.69 | 87.23 | 7.54 | 37.91 | 153.95 |
| S | 262.88 | 65.37 | 142.56 | 401.79 | 142.56 | 256.45 | 401.79 |
| SCL | 30.27 | 20.93 | 7.13 | 100.93 | 7.13 | 24.89 | 100.93 |
| SL | 28.80 | 4.36 | 21.13 | 37.96 | 16.24 | 28.83 | 44.62 |
| SiL | 5.32 | 1.46 | 2.94 | 8.86 | 1.48 | 5.14 | 12.72 |
| SiC | 1.99 | 1.26 | 0.43 | 5.13 | 0.17 | 1.69 | 11.66 |
| SICL | 5.83 | 3.28 | 1.42 | 13.40 | 0.70 | 5.15 | 23.77 |
| All Grps | 40.26 | 78.71 | 0.32 | 326.59 | 0.00 | 11.25 | 401.79 |

Table 3. Ksat (mm h-1): bootstrap statistics for the ten USDA textural classes (N = 1,000). StdDev: standard deviation; 95% CI: 95% confidence interval of the mean. Ksat estimates with the PTF of Brakensiek et al. (1984).



In Emilia-Romagna the map of saturated hydraulic conductivity (Ksat) is available for the plain area of the region¹¹ (Fig. 9).



Figure 3. Example of query of the Ksat map on the CARTPEDO web page.

A I.III Air entry pressure

Air entry pressure (PSI_e, cm) corresponds to the matric potential value at which air begins to enter the soil porous system, causing a switch from gravity driven flow (saturation conditions) to capillary flow (unsaturated conditions). Its value is one of the chief factors controlling soil retention properties and determines the inflection point of the soil-water retention curve. For this reason, it compares explicitly in the analytical description of the retention curve in the model proposed by Brooks and Corey (1964) and by van Genuchten

¹¹http://mappegis.regione.emilia-romagna.it/gstatico/documenti/dati_pedol/ksat_pianura.pdf

(1980). Fine textured soil have high values of air entry pressure ($PSI_e > 100 \text{ cm}$), while the opposite happens in coarse texture soils ($PSI_e < 20 \text{ cm}$).

Using a data base of 445 retention curves from Italian soils, Ungaro et al. (2014) calibrated a PTF to estimate PSI_e> using GMDH statistical networks (Ivakhnenko, 1968). The calibrated network has the following sructure:



Input PTF: L%, S%, CO% (log), PORO1

S%: sand % L%: silt % CO%: carbonio organico % (Log) *PORO1*: porosity %, *PORO1*= (1-(*BD*/(2.7*(1-(*Corg*%*10^-2)) + *Corg*% *10^-2)))*0.96 BD: bulk density (Mg m⁻³), measured or estimated

Normalization input 1

A = -1.55514315777641+ 0.0439626330192209*S% B = -1.62156839186953+ 0.000826045814054491*L% C = 5.88501454719847+ 12.6194730338606*PORO1

Output first network node

D = -0.568439426027443+ -0.339618598889681*A + 0.0850629667172664*B + - -0.327793522823292*C + 1.18970550060609* A^2 + 0.576355024165541*B^2 + 0*C^2 + -0.198584356240143*A*B + 0.301041218929671*A*C + -0.10527882324184*B*C + --0.661480855965559* A*B*C + 0.151788905416509*A^3 + 0.133497668914664*B^3 + -0.0145722698122465*C^3 + 1.11203822431696*A^2*B+ 0.964631529651623* A*B^2+ 0.0684388124744497*A*C^2+ 0.20749615690423* A^2*C+ 0.429023990805545*B^2*C+ 0.0265885830908164*B*C^2

Normalization input 2

E= 0.0187145139027159+ 2.11251970495063*LogC

Output second network node

```
F = 0+ 1.15847606797297*D + 0.200090177126999*E + 0.0866162637992406*D^2 + -0*E^2 + 0*D*E + -
0.0782508492875681*D^3 + -0.0274983695657443*E^3 + --0.0487893822277778*D^2*E + -
0.0762940081491734*D*E ^2
```



*PSI*_e = 54.443993993994+ 41.7053965834241* F

(MIN=2.658, MAX = 200)

A I.IV Available water capacity (AWC)

Available water capacity (Available Water Capacity, AWC) is the maximum amount of water available in a soil that can be used by plants. It is calculated as the difference between the water content at field capacity (field capacity, FC) and the one at wilting point (Wilting point WP). The first is conventionally placed at 333 cm tension (-33 kPa or -.33 bar), the second at 15000 cm tension (-1500 kPa or -15 bar). The available water capacity is required for the calculation of the indicator CLI, the water content to the field capacity for the calculation of the indicator WAS.

Using a database of 445 retention curves from Italian soils, Ungaro et al. (2014) calibrated two PTFs to estimate the water content at field capacity and the water content at wilting point. The difference in water content at the two points return the available water capacity.

I.IV.I Water content at 333 cm tension (m³/m³)

Input PTF : Dg, C org %, PORO1, L%

Dg : particles size mean diameter

C org% : organic carbon content % *PORO1*: estimated saturation % , *PORO1*= =(1-(*BD*/(2.7*(1-(*Corg*%*10^-2)) + *Corg*% *10^-2)))*0.96 BD: bulk density (Mg m⁻³), measured or estimated *L*%: silt %

Normalization input 1

A = 3.8102814236164 + 0.827378421952734 *ln(Dg) B = -0.491141860677084 + 0.367776345566818 * Corg% C = -5.88752433612624 + 13.0483582639121 * PORO1

Output first network node

Normalization input 2

E = -1.3033911325751 + 9.74232503307444E-06 * L%^2

Output second network node

F = 0 + 0.99590304675235 *D + 0.0852214730608352 *E + 0*D^2 + 0*E^2 + 0*D*E + 0*D^3 + - 0.0297749925104875 *E^3 + 0*D^2*E + 0*D*E ^2

CI_333 = 0.34296644295302 + 0.0984845588190126 * **F**

(MAX= 0.671, MIN= 0.064)

I.VI.II Water content at 15000 cm tension (m³/m³)

Input PTF: Dg, C org %, BD

Dg : particles size mean diameter *C* org% : organic carbon content % BD: bulk density (Mg m⁻³), measured or estimated

The estimation algorhythm has the following structure:

Normalization input 1

A = 3.77140361228726 + 0.819740344988767 *ln(Dg) B = -0.49157638336218 0.367695186350225 * Corg% C = -2.905574766004 + 0.947767333204745 * BD^3

Output first network node

```
 D = 0 + -0.763103574848119 *A + 0.236868672084561 *B + 0. -0.0731674247644929 *C + 0* A^2 + -0.434887427284714 *B^2 + -0.105886229669014 *C^2 + 0.302936372100644 * A*B + 0 *A*C + -0.483229853413334 *B*C + 0.0494789265032567 * A*B*C + 0 *A^3 + -0.164404279418551 *B^3 + 0.0589897728741078 *C^3 + -0.221540878505337 * A^2*B + 0.241483606228241 * A*B^2 + 0 * A*C^2 + 0 *A^2*C + -0.334515879151902 *B^2*C + 0.150148733944991 *B*C^2
```

CI_15000 = 0.236463087248322 + 0.104480408320589 * **D** (MAX. 0.546; MIN. 0.012)

A I.V Cation exchange capacity

The cation exchange capacity (CSC, cmol kg-1) is required for the calculation of the indicator BUF. In the absence of measured values, the CSC can be estimated by using pedotransfer functions. Several PTFs have been calibrated to estimate CSC from physico-chemical properties (Breeuwsma et al., 1986; Manrique et al., 1991; Bell and Van Keulen, 1995; McBratney et al., 2002); in most cases these models are based on a linear relationship between CSC, organic matter (or organic carbon) content, and clay content. Calzolari et al. (2016) calibrated the following report on a database of 3269 observations from Italian soil:

CEC (cmol kg⁻¹) = 6.332 + 0.404 Clay % + 1.690 C org % (R² = 0.75)



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ANNEX II. SOIL ECOSYSTEM SERVICES ASSESSMENT

Depending on available data, soil ecosystem services assessment can follow three different approaches:

- 1. Being based on data derived from ad hoc urban soils survey;
- 2. Being based on available soil maps and data from benchmark soil profiles;
- 3. Being based on available thematic maps derived from soil maps or other soil information in raster or vector format (tiles).

A II.I Assessment based on ad hoc soil survey

This case has been briefly described in paragraph 2.2.1 and more in details in the deliverable of action B 1.3 (http://www.sos4life.it/documenti/). It requires good processing capacity, as the necessary thematic layers (soil texturural fractions, pH, organic carbon) should be derived from the analyzed data, following the urban soil survay. The soil capability map can be derived from local data or from already available maps. The derivation of thematic maps from soil data is beyond this discussion and it is necessary to refer to the Digital Soil Mapping techniques. Examples of this type of technique can be found in numerous publications (Ballabio et al, 2016; Boettinger at al, 2010; Dobos et al, 2010; Hengl et al, 2014; Lagacherie et al, 2006; McBratney et al, 2003; Orgiazzi et al., 2018; Scull et al., 2003). As an alternative to digital soil mapping techniques, the analyzed data can be used to calculate the indicators for the different land uses found in urban soils (e.g. parks, roundabouts, private green areas, sports green areas, agricultural areas).

A II.II Assessment based on available soil maps and benchmark soil profiles

This method was used in the SOS4LIFE project to draw up the soil ecosystem services maps of the municipalities of Forlì and San Lazzaro di Savena. In the case of the Emilia-Romagna region, the 1: 50,000 soil map (available for 71% of the territory) is accompanied by local chemical-physical analyzes for each soil profile present in the map polygons (unambiguously described). In the case of other regions, it is instead necessary to refer to the analyzes that accompany the benchmark profile of each soil described in the map and to process the data in terms of map units (i.e. groups of polygons with similar soils).

The methods of calculation using this method have been described in the document "Local representative sites of the soils of the plain, the lower and middle Apennines of Emilia-Romagna" (Tarocco et al, 2018). The document also indicates how to download the data.

The input data necessary for the assessment are:

- Soil map;
- Analysis of reference soil profile (skeleton, textural fractions, organic C %);
- Soil capability map;
- Map of the average depth of the shallow water table (in the case of lowland areas).

A II.III Assessment based on thematic maps in raster or vector tiles format

With this assessment method the soil map is not strictly necessary. This method was used to calculate the SEs of the Emilia-Romagna plain (Calzolari et al, 2016), but it can be implemented at local scale if the information is sufficiently detailed. In the case of the Emilia-Romagna region, the necessary thematic maps (with the exception of pH) are available in the plain area in vector format with cells of 500 m x500 m. This makes the final maps more detailed than the previous method. The data can be downloaded directly from the Geocatalogue. The level of detail available in the other regions is very variable.



The necessary input data are:

- texture and skeleton map (topsoil and subsoil);
- map of organic carbon content (topsoil and subsoil);
- map of organic carbon stock (topsoil and subsoil): this layer can be derived from the two previous maps;
- pH map (topsoil and subsoil);
- soil capability map;
- map of the average depth of the shallow water table (in the case of lowland areas).

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ANNEX III. DEFINITION AND ASSESSMENT OF THE QBS-ar INDEX

Soil animals have different degrees of adaptation to hypogean life. They display specific adaptation features such as: the absence of visual organs, the lengthening and flattening of the body, the shortening of the sensory and locomotor appendages, the reduction or disappearance of some appendages (such as the furca, a organ used for jumping in *Collembola*, or metathoracic wings in *Coleoptera*), the presence of sensory organs to detect the degree of humidity, depigmentation or crypto-pigmentation to merge with soil particles as in mites, reduction or disappearance of sensory organs that absorb light radiation (Menta, 2012). The various groups are defined by biological forms characterized by the same series of convergent characters. These organisms have therefore adapted to the soil edaphic environment and can no longer survive outside it (Parisi et al., 2005).

Micro-arthropods play an important role in the trophic chain and energy flow that accompanies the last phases of the organic matter cycle. They are involved in the crushing of plant residues, in the demolition and translocation of organic matter, in the control and dispersion of micro-flora and micro-fauna, and are predators of micro- and the meso-fauna (Menta, 2012). We can therefore consider them good bio-indicators. The degree of adaptation of the biological forms to life in the soil varies according to the presence and combination of the characters mentioned above. Its quantification uses a scale of reference scores called EMI (EcoMorphological Indexes). For each character indicating adaptation to the soil environment, a score is assigned, from a minimum of 1 to a maximum of 20, depending on whether the morphological features are weakly or strongly adapted to the soil environment. Therefore, in QBS-ar there is not so much reference to taxonomy, but rather to the degree of adaptation to the soil environment and to evolutionary convergence. For the features that indicate the greatest degree of adaptation to soil conditions an EMI score of 20 is assigned (edaphic), while a score of 1 (epi-edaphic) is assigned to slightly adaptation features. All biological forms characterized by intermediate conditions have a score equal to their degree of specialization (emi-edaphic). Table 11 provides a list of EMI scores.

| Group | Order | EMI score |
|-------------|--|-----------|
| Epi-edaphic | Dermaptera, Psocoptera, Thysanoptera, Other holometaboluos insects (adults) Hymenopera, Araneae | 1 1-5 |
| | Orthoptera, Emiptera | 1-10 |
| Emi-edaphic | Collembola, Coleoptera | 1-20 |
| - | Blattaria | 5 |
| | Embioptera, Diptera (larvae), Other holometaboluos insects (larvae), Opiliones, Isopoda | 10 |
| Edaphic | Chilopoda, Diplopoda | 10-20 |
| | Protura, Diplura, Acari, Palpigradi, Pseudoscorpiones, Pauropoda, Symphyla | 20 |

Table 4. EMI scores for soil per micro-arthropods (Parisi, 2001).

When in a soil sample there are different biological forms belonging to the same group, only the highest EMI value (maximum EMI) is taken into account. The biological soil quality index (QBS-ar) is a total score attributed to a soil sample and is given by the sum of all the individual EMI scores. The application of the QBS-ar method is divided into 5 five steps: i) sample collection, ii-iii) extraction and conservation of micro-arthropods, iv) determination of the biological forms contained and finally v) calculation of the QBS-ar index.

In the absence of direct measures, land use can be used (e.g. CORINE Land Cover, 4th level), attributing average QBS-ar values based on land use classes based on data from literature (Menta et al., 2008):

- High (QBS-ar, 150-250) for permanent meadows and pastures, woodlands and peat bogs;
- Medium (QBS-ar, 100-150) for agricultural lands in rotation with meadows and minimum tillage;
- Low (QBS-ar, 60-100) for other land uses.



The indicator proposed as a proxy for the estimation of soil biodiversity (BIO) also takes into consideration the organic C content and bulk density, and has the following form:

 $BIO_{0-1} = (LogOC_{0-1} - BD_{0-1}) + QBSar_{0-1}$

with $QBSar_{0-1}$ equal to 1, 0.5 and 0.25 respectively for high, medium and low biodiversity depending on the prevalent land use.

6. AUTHORS

CNR Ibimet Costanza Calzolari, Fabrizio Ungaro, Anita Maienza

Regione Emilia-Romagna Servizio Geologico Sismico e dei Suoli Nazaria Marchi, Paola Tarocco

Have joined the work of the working group Action B1.3

Comune di Carpi Norberto Carboni, Attilio Palladino

Legambiente E.R. Lorenzo Frattini

ANCE E.R. Francesca Ferrari

Regione Emilia-Romagna Servizio Geologico Sismico e dei Suoli Francesco Malucelli

FMI Claudio Maltoni



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