RegioneEmilia-Romagna

Ibimet
Consiglio Nazionale delle Ricerche

Ecosystem services of urban soils

C. Calzolari, S. Baronti, M. Lanini, A. Maienza , M. Nardino , F. Ugolini, F. Ungaro **CNR IBiMet**

P. Tarocco, N. Marchi **SGSS Regione Emilia-Romagna**

SOS4LIFE
SAVE OUR SOIL FOR LIFE

WFUF – World Forum on Urban Soils
Mantova, November 29th 2018

World Forum on Urban Forests Mantova 2018

LIFE15 ENV/IT/000225

1. Introduction

- Ecosystem services (ESs) research is currently focusing more and more on soils but few studies have focussed on the **linkages between soil properties and ES provision** and the use of soil data is often minimal (Adhikari & Hartemink, 2016)

- Despite the centrality of its role in ESs supply, soil is still an **overlooked component in ESs** studies as well as in policy level decisions (Hewit et al., 2015)

- Many authors emphasized the need for soil ESs assessment and for promoting **soil-ecosystem linkage** in the development of land resources policy and management (Bouma et al., 2015; Mc Bratney et al, 2014; Lal, 2013; Robinson et al., 2012)

- The **contribution of urban soils to human well-being** in terms of provision of ecosystem services is largely unknown and very rarely accounted for in urban planning to enhance the sustainable development of urban ecosystem (Morel et al., 2014) and, although fundamental, soil is considered a secondary compartment beyond vegetation.

2. Introduction

- Among the goals of the EU funded LIFE project SOS4LIFE is the development of methods for the assessment and mapping of soil ecosystem services in urban and periurban areas and the impact of soil sealing on the provision of ecosystem services.
- To this aim we surveyed, sampled and analyzed the urban and periurban soils of the municipality of Carpi (Emilia Romagna, NE Italy) and applied a methodology developed at regional scale (Calzolari et al., 2016) and tailored to tackle the observed variability in soil properties to estimate and map a set of indicators to describe the provision of a number of soil based ecosystem services.
- Sampled soils include:

(1) soils that are composed of a mixture of materials differing from those in adjacent agricultural or forest areas, and that may present a surface layer >50 cm, highly transformed through mixing, importing, and exporting material, and by contamination;

(2) soils in parks and gardens that are closer to agricultural soils but have different composition, use, and management than agricultural soils;

and **(3)** soils that result from various construction activities in urban areas and that are often partially or completely sealed.

3. Soil Ecosystem Services: conceptual framework

SOIL (Natural/$_{artificial}$ Capital)
Characteristics and properties:
depth, slope, aspect,
Texture (sand, silt, clay),
stoniness,
Soil organic matter,
structure,
Bulk density,
porosity, water retention
Hydraulic conductivity,
fertility, ….

EXTERNAL CONTROLS
Natural
(Climate, geology, topography…)
Anthropic
(Land use,
Agricultural management, …)

PROCESSES
Water cycle
Nutrients cycles
Biological activity
Aggregate formation
Gas exchange

FUNCTIONS
Support human activities
Habitat and biodiversity
Fluxes regulation
C sequestation
Storage H_2O
Food and fibers
Raw materials

ECOSYSTEM SERVICES
(benefits to human populations)
Provisioning
Supporting, Regulating
Cultural

BENEFITS
Food security
Environmental quality
Social stability
Geo-hydrological protection
Urban quality
Well-being

processes
controls
fluxes

3. Soil Ecosystem Services: from properties to ESs

Soil properties Soil stocks - SNC

- Bulk density
- Capability class
- Clay content
- CEC
- Depth
- K sat
- Organic C
- Peat layer
- pH
- RETC
- Sand content

- Land Use
- Avg GW depth

Soil Indicator (soil processes)	Soil function[a] (output of processes)	Soil contribution to ESs[b]	ESs categories[c]
Potential habitat for soil organism	Biodiversity pool	Habitat for soil organisms	1.BIO Supporting
CEC Soil reaction Rooting depth	Storing ,filtering and transforming nutrients, substances and water	Nutrient and pollutant retention and release; Natural attenuation	2.BUF Regulating
Soil evaporation potential	Storing ,filtering and transforming nutrients, substances and water	Microclimate regulation	3.CLI Regulating
C stock C sequestr. Pot.	Carbon pool	C stock (actual) C sequestration (pot.)	4.CST & CSP Regulating
Land capability map	Biomass production	Food provision	5.PRO Provisioning
Soil bearing capacity	Physical and cultural environment	Supporting human activities and infrastructure	6.SUP Provisioning Supporting
Infiltration capacity	Storing ,filtering and transforming nutrients, substances and water	Water regulation Runoff/flood control	7.WAR Regulating
WC@FC Presence of WT	Storing ,filtering and transforming nutrients, substances and water	Water regulation Water storage	8.WAS Regulating Provisioning

3. Soil Ecosystem Services: ESs Indicators

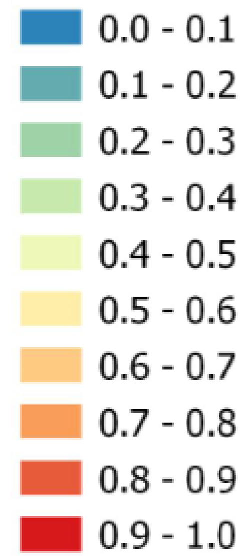
- $WAS_{0-1} = (WC_{FC} * 1-sk)_{0-1}$ for water table deeper than 100 cm, and
$WAS_{0-1} = (WC_{FC} * 1\text{-}sk)*WT/100$ for water table within the first 100 cm
- $BIO_{0-1} = (\text{Log } OC_{0-1} - BD_{0-1})\ QBS_{ar\ 0-1}$
- $WAR_{0-1} = \log Ksat_{0-1} - PSIe_{0-1}$
- $CLI_{0-1} = \log AWC_{0-1} + WT_{0-1}$
- $CST_{0-1} = \log (SOC*BD*0.3*(1\text{-}sk))_{0-1}$
- $BUF_{0-1} = \text{Log } CSC(pH; sk)_{0-1}$

with pH<6.5 reduction by 0.25 or 0.5 depending on CSC and skel>30% by 0.25
for water table deeper than 100 cm, and
$BUF_{0-1} = \text{Log } CSC(pH; sk)_{0-1}*WT/100$
in case of occurrence of a shallow water table within the first 100 cm of soil depth, being WT the average water table depth (cm).

Interval normalization

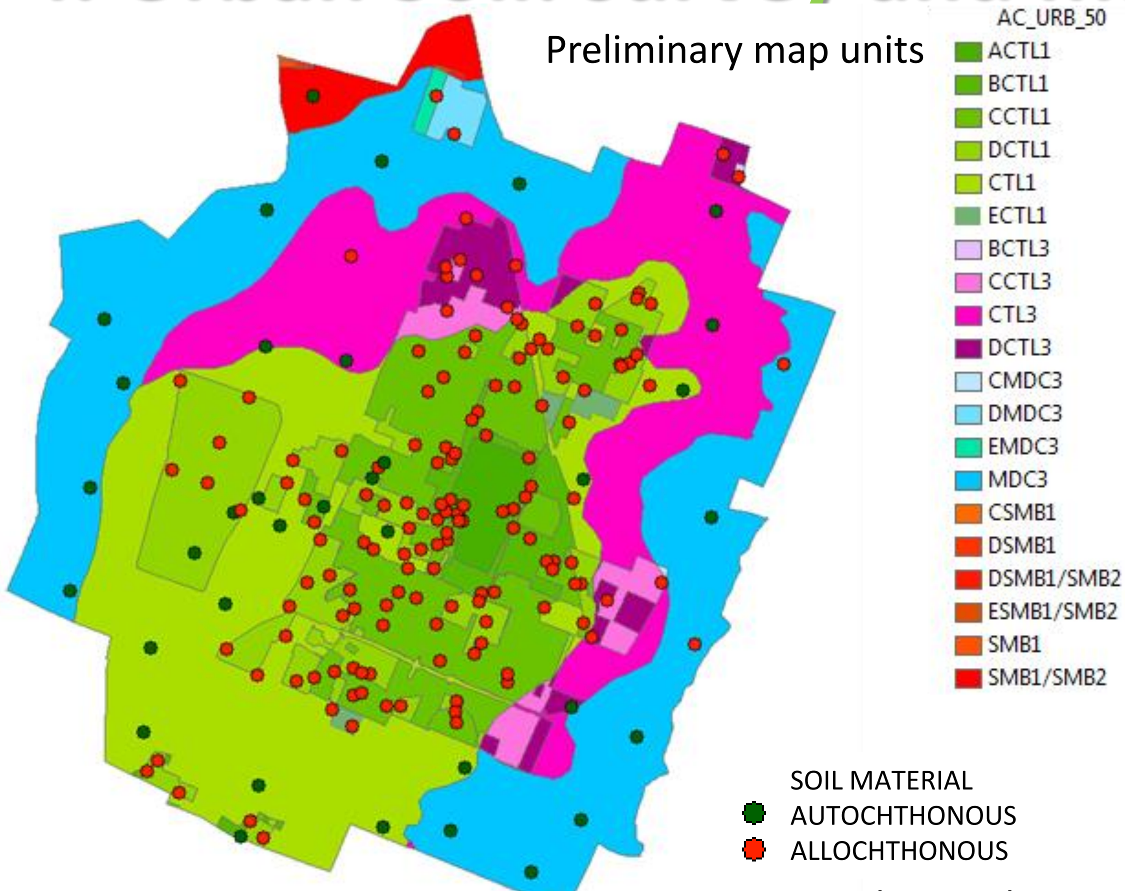
$Xi' = Xi - Xmin/Xmax - Xmin$

where Xi' is the standardised [0–1] value, Xi is the actual value, Xmin and Xmax are the maximum and the minimum respectively of each considered variable in the dataset. The formula gives high priority (i.e. values close to 1) to higher values of the considered indicator; the lowest value, 0, does not indicate that the function is not provided, but that it is the lowest in the considered area.

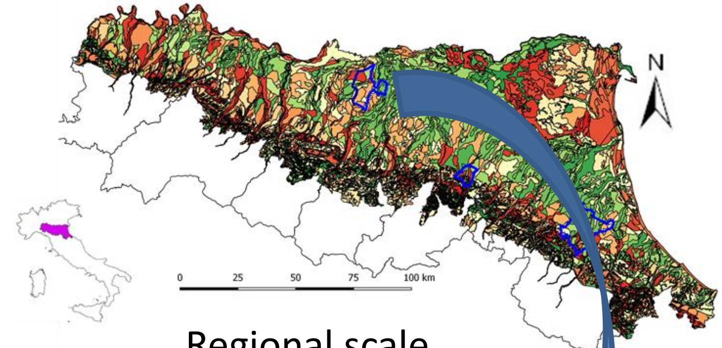


4. Urban Soil: survey and mapping

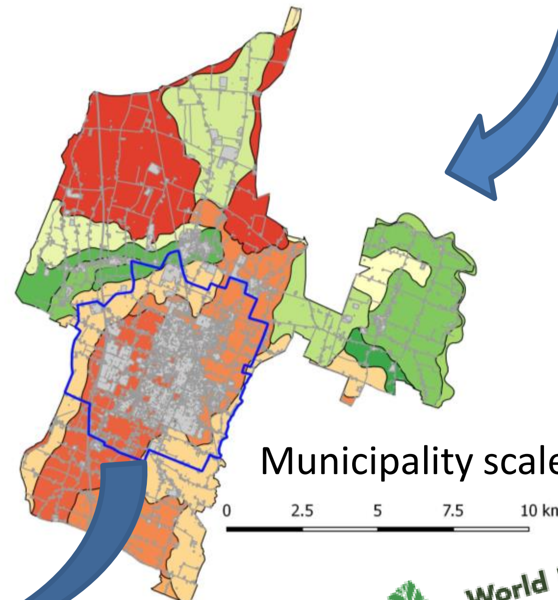
Preliminary map units



Urban scale



Regional scale



Municipality scale

179 SAMPLING SITES FOR ROUTINE ANALYSIS
40 SITES FOR HEAVY METALS CONTENT
20 sites for Ksat and SBQ + 6 profiles

Regione Emilia-Romagna

Ibimet Istituto di Biometeorologia – Consiglio Nazionale delle Ricerche

4. Urban Soil: survey and mapping

E7425P0004
BCP1

E7425P0005
PET1

E5034Q0003
CRP

19 SAMPLING SITES FOR KSAT, BD, QBSar
6 SOIL PROFILES

E7425P0001
LUC3

E7425P0002
LUC3

E7425P0003
BCP1

urban-BCP1

urban-CRP-PET0

LUC1-urban

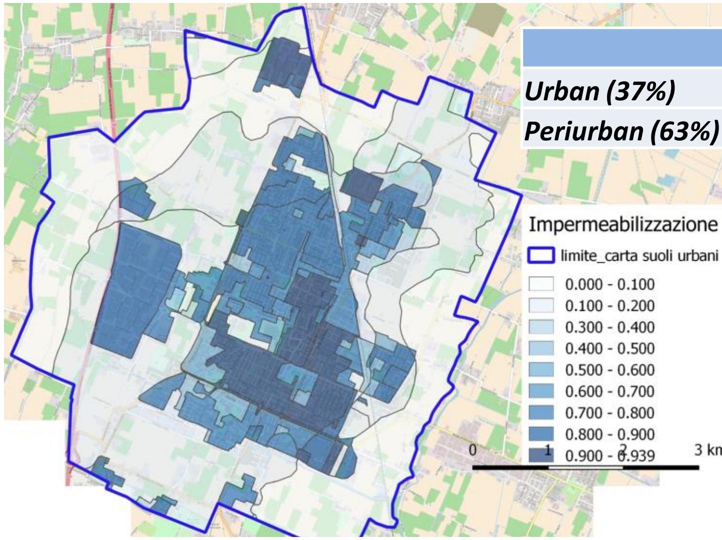
PET2/LUC2/urban

SOS4LIFE
SAVE OUR SOIL FOR LIFE

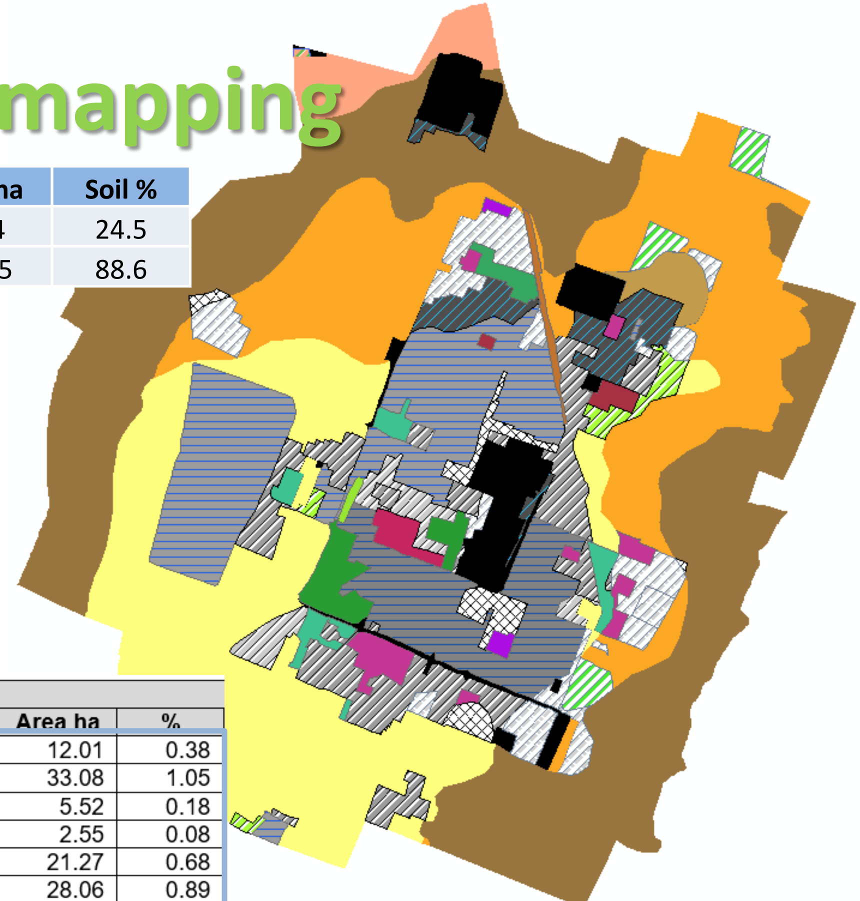
World Forum on Urban Forests Mantova 2018

Regione Emilia-Romagna

4. Urban Soil: survey and mapping

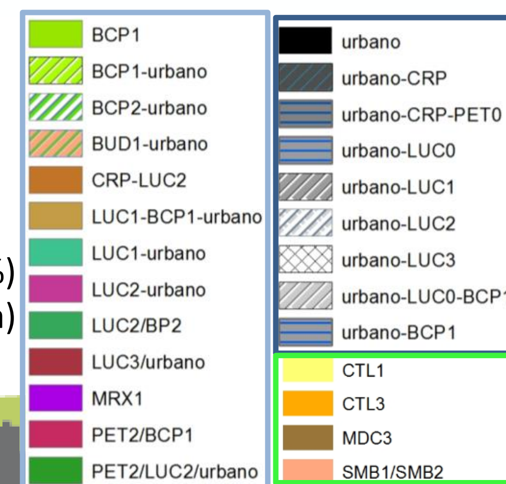


	Tot ha	Built up	Soil ha	Soil %
Urban (37%)	1162	877	284	24.5
Periurban (63%)	1981	226	1755	88.6



Urban area			
SMU	% imperm.	Area ha	%
Urban	93,88	118.90	3.78
Urban-BCP1	81,82%	139.76	4.45
Urban-CRP	82,09%	67.19	2.14
Urban-CRP-PET0	90,26%	139.34	4.43
Urban-LUC0	84,51%	134.42	4.28
Urban-LUC0-BCP1	71,49%	37.38	1.19
Urban-LUC1	79,97%	168.25	5.35
Urban-LUC2	85,08%	107.07	3.41
Urban-LUC3	71,17%	34.65	1.10
CRP-LUC2	34,27%	7.94	0.25
LUC1-BCP1-Urban	32,00%	24.11	0.77
LUC1-Urban	44,68%	29.02	0.92
LUC2/BP2	13,08%	10.13	0.32
LUC2-Urban	54,20%	32.36	1.03
LUC3/Urban	62,92	8.06	0.26

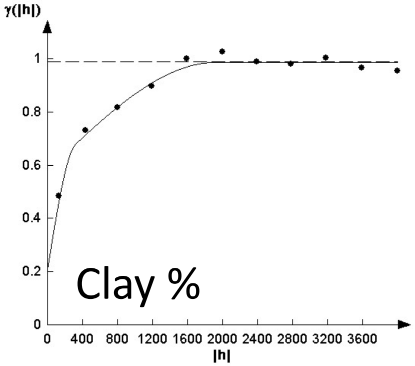
Urban area			
SMU	% imperm.	Area ha	%
PET2/BCP1	13,16%	12.01	0.38
PET2/LUC2/Urban	50,38%	33.08	1.05
MRX1	55,59	5.52	0.18
BCP1	8,13%	2.55	0.08
BCP1-Urban	34,22%	21.27	0.68
BCP2-Urban	10,37%	28.06	0.89
BUD1-Urban	24,30%	0.83	0.03
		1161.9	**36.97**
Periurban area			
SMU	% imperm.	Area ha	%
CTL1	15,98%	566.98	18.04
CTL3	11,31%	491.47	15.64
MDC3	8,62	869.73	27.67
SMB1/SMB2	8,47	52.75	1.68
		1980.93	**63.03**

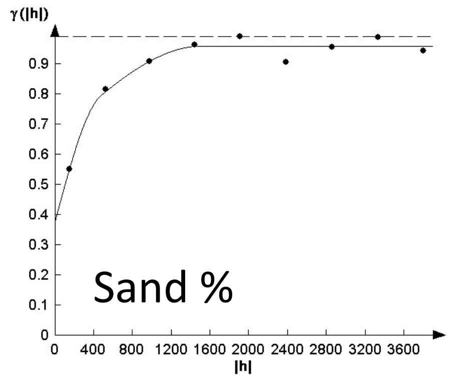


SMUs with prevalent soil sealing (70-90%) represent 81% of the urban area (947 ha)

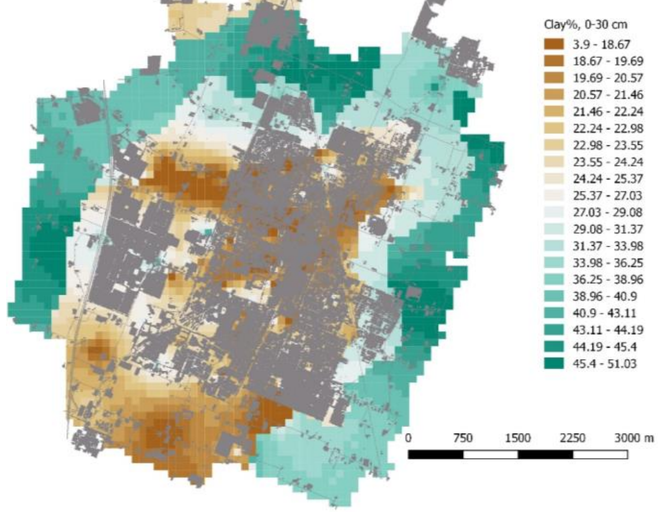
SOS4LIFE SAVE OUR SOIL FOR LIFE

5. Soil properties & functions

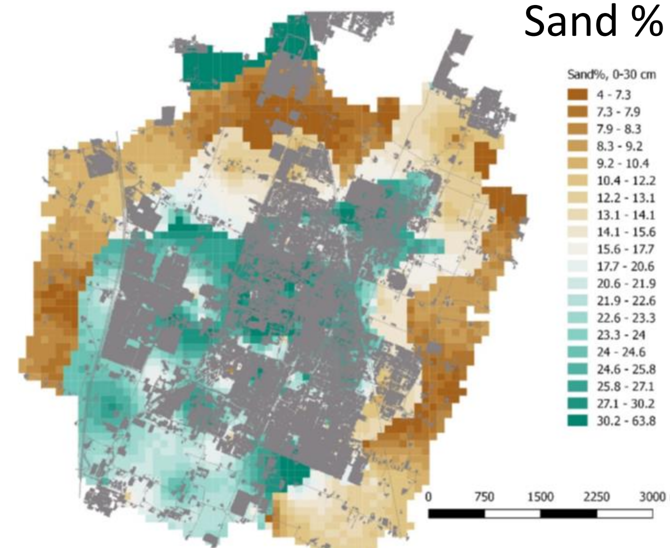




Clay %

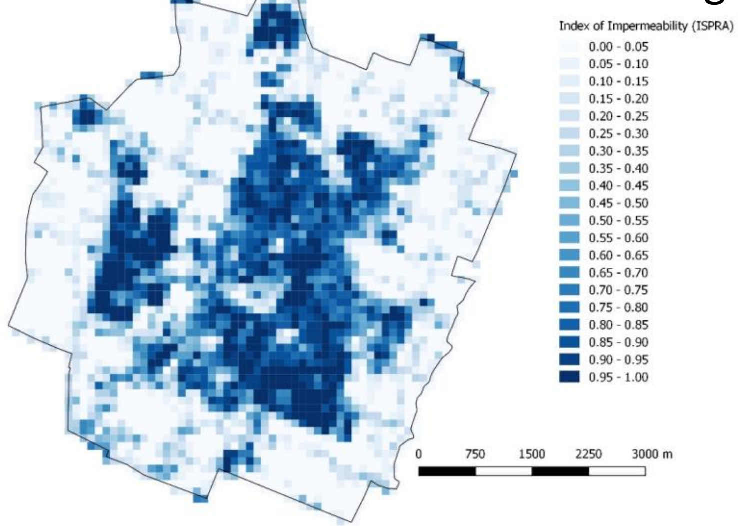


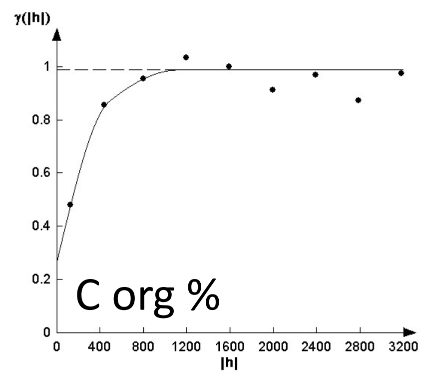
Sand %



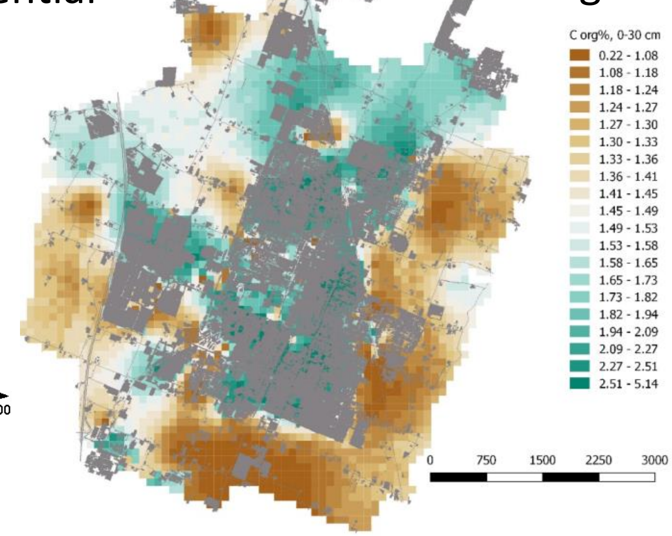
Geostatistical interpolation via sequential gaussian simulation

Soil sealing





C org %

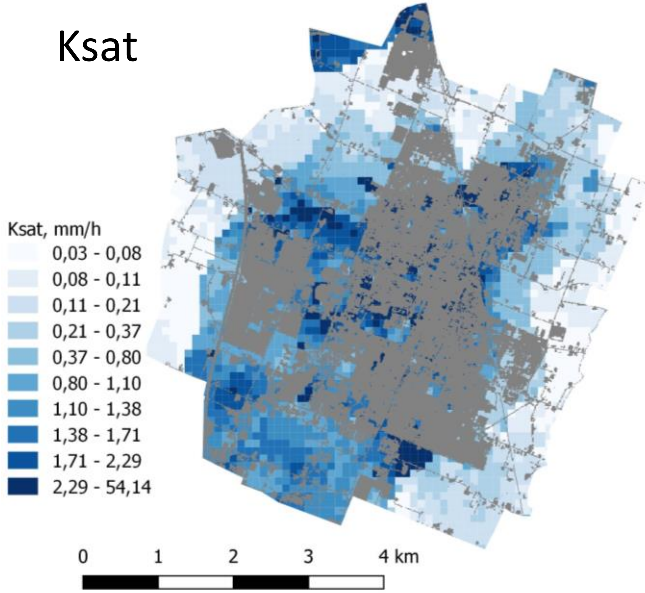


RegioneEmilia-Romagna

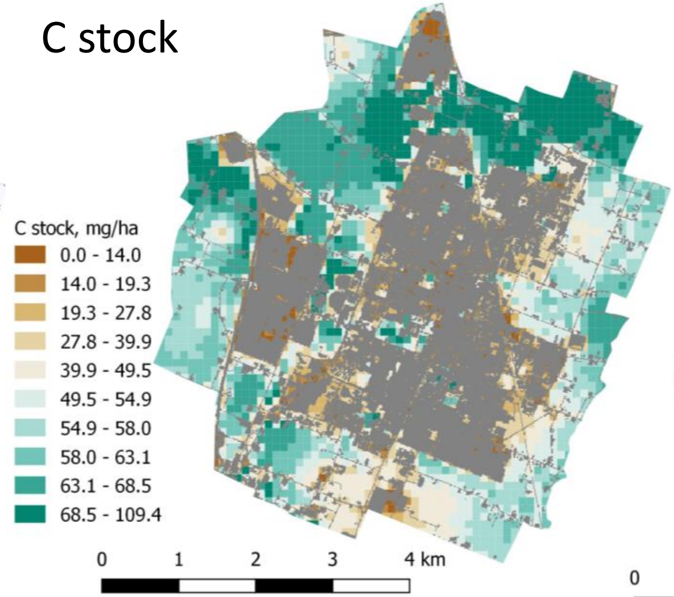
5. Soil properties & functions

Ibimet
Consiglio Nazionale delle Ricerche

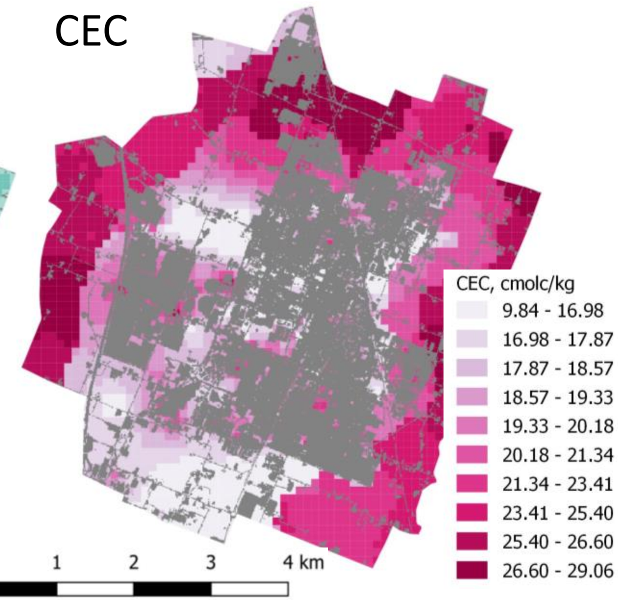
Ksat



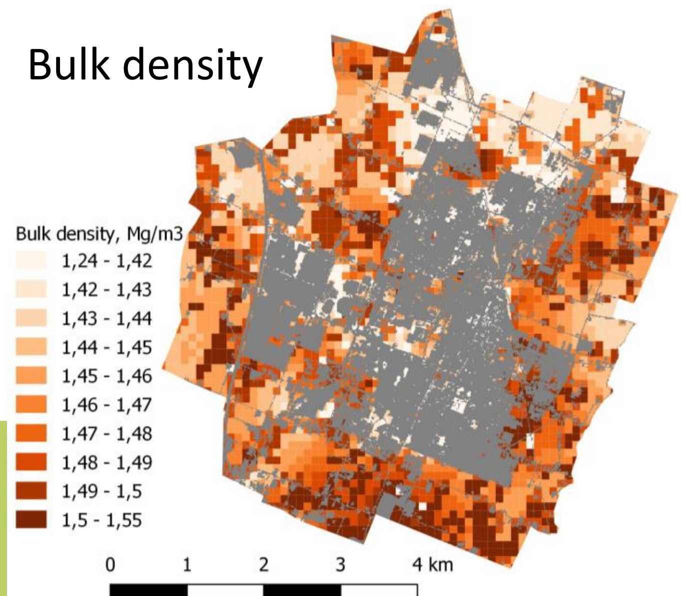
C stock



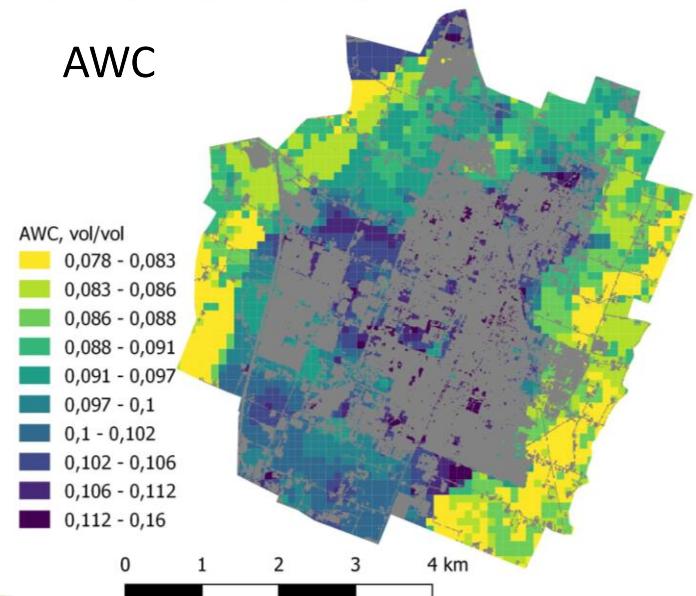
CEC



Bulk density



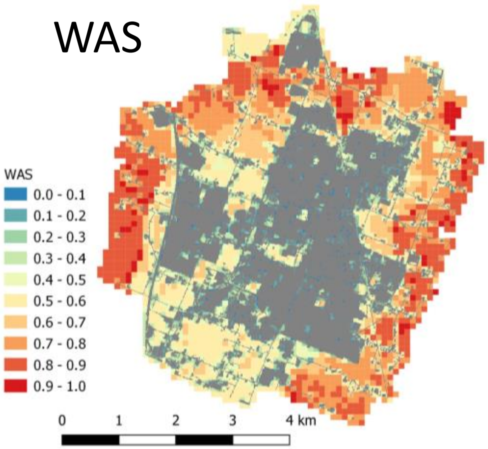
AWC



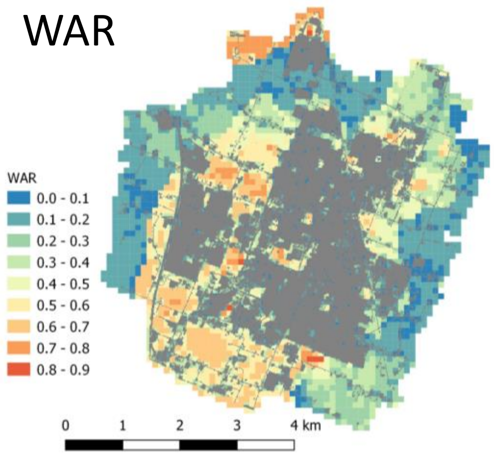
SOS4LIFE
SAVE OUR SOIL FOR LIFE

6. Soil Ecosystem Services

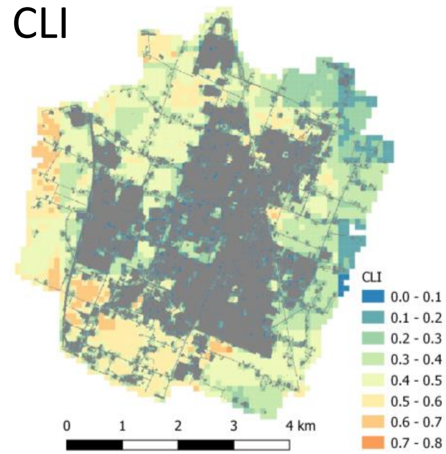
WAS



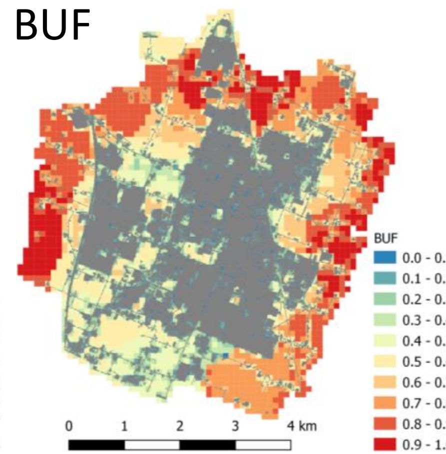
WAR



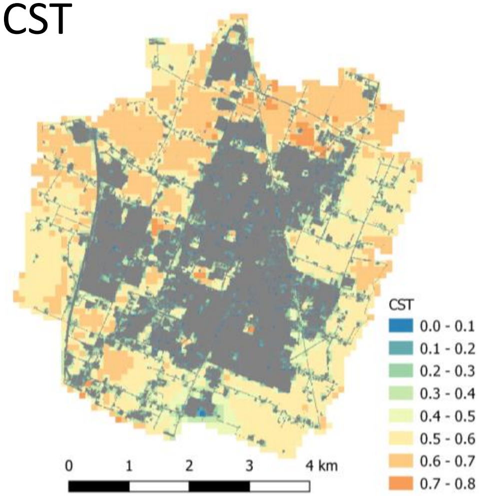
CLI



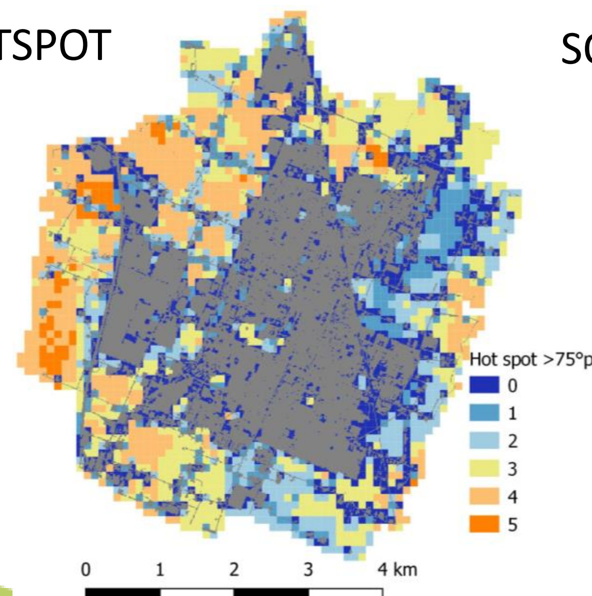
BUF



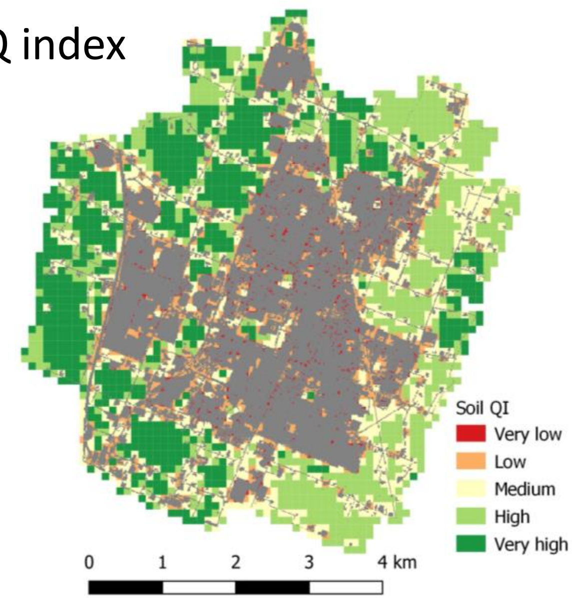
CST



HOTSPOT



SQ index

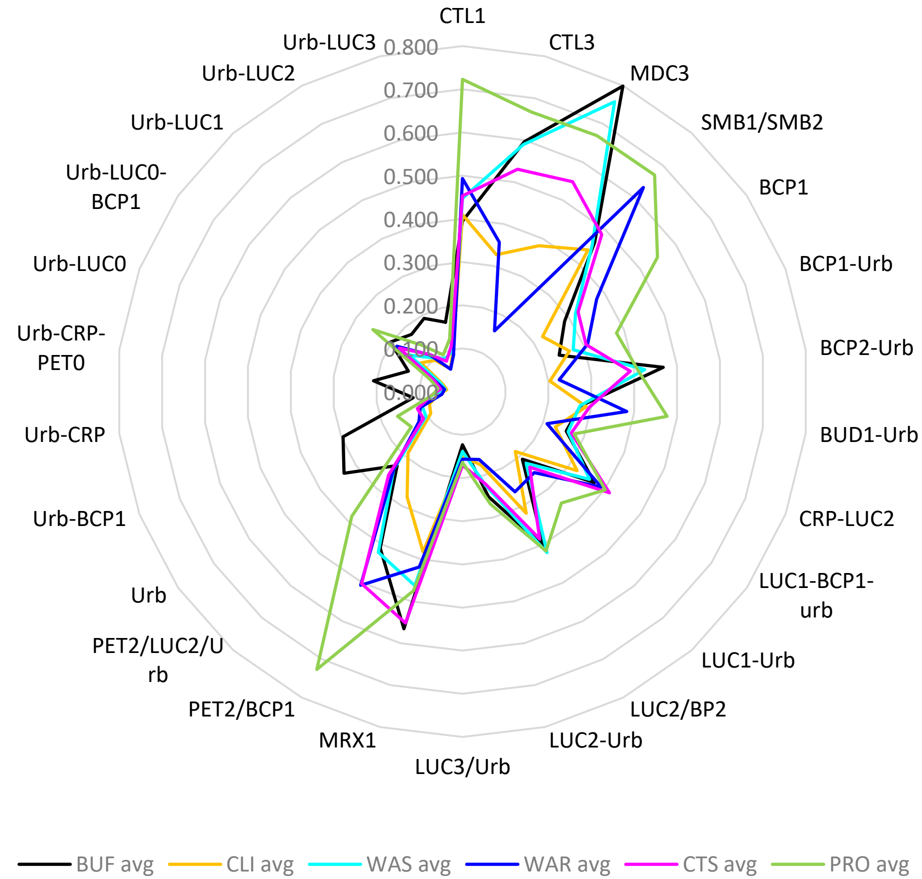


SOS4LIFE
SAVE OUR SOIL FOR LIFE

6. Soil Ecosystem Services

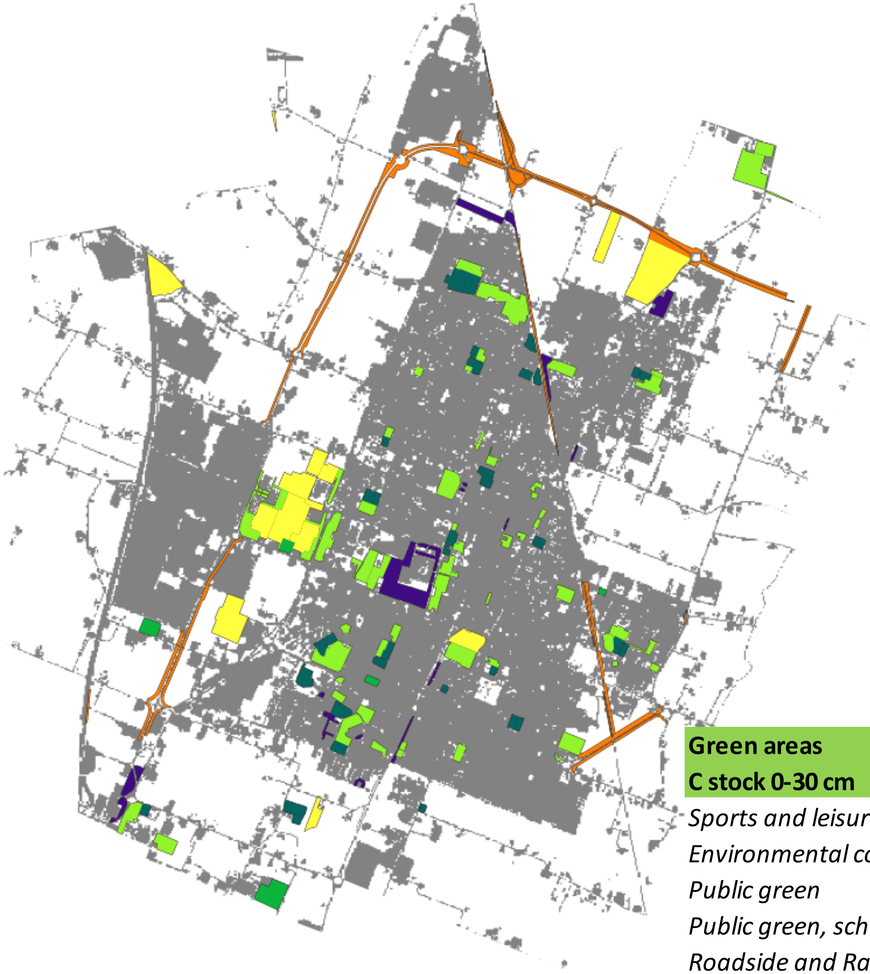
Area	SMU	ha	BUF	CLI	WAS	WAR	CTS	HotSpot	HotS /ha	IQ
Cropland	CTL1	567	0.395	0.410	0.447	0.493	0.453	449	0.79	2.20
Cropland	CTL3	477	0.596	0.327	0.589	0.356	0.531	330	0.69	2.40
Cropland	MDC3	867	0.799	0.381	0.758	0.159	0.549	800	0.92	2.65
Cropland	SMB1/SMB2	53	0.462	0.439	0.452	0.632	0.486	48	0.91	2.47
Urban <60%	BCP1	3	0.287	0.225	0.318	0.377	0.325	3	1.18	1.53
Urban <60%	BCP1-Urb	21	0.239	0.265	0.274	0.310	0.306	10	0.47	1.39
Urban <60%	BCP2-Urb	28	0.468	0.204	0.424	0.226	0.391	9	0.32	1.71
Urban <60%	BUD1-Urb	1	0.275	0.289	0.274	0.383	0.296	1	1.21	1.52
Urban <60%	CRP-LUC2	8	0.257	0.230	0.262	0.210	0.270	1	0.13	1.23
Urban <60%	LUC1-BCP1-urb	24	0.371	0.322	0.358	0.389	0.413	16	0.66	1.85
Urban <60%	LUC1-Urb	29	0.209	0.185	0.222	0.250	0.234	2	0.07	1.10
Urban <60%	LUC2/BP2	10	0.404	0.318	0.421	0.262	0.385	3	0.30	1.79
Urban <60%	LUC2-Urb	32	0.250	0.174	0.225	0.162	0.220	3	0.09	1.03
Urban <60%	LUC3/Urb	8	0.124	0.151	0.139	0.156	0.171	0	0.00	0.74
Urban <60%	MRX1	6	0.566	0.382	0.463	0.418	0.552	2	0.36	2.38
Urban <60%	PET2/BCP1	12	0.410	0.276	0.420	0.507	0.502	9	0.75	2.11
Urban <60%	PET2/LUC2/Urb	33	0.229	0.190	0.241	0.240	0.258	6	0.18	1.16
Urban >60%	Urb	119	0.333	0.089	0.102	0.122	0.110	34	0.29	0.76
Urban >60%	Urb-BCP1	140	0.295	0.082	0.099	0.105	0.111	12	0.09	0.69
Urban >60%	Urb-CRP	67	0.115	0.057	0.071	0.048	0.071	0	0.00	0.36
Urban >60%	Urb-CRP-PET0	139	0.208	0.036	0.041	0.042	0.050	1	0.01	0.38
Urban >60%	Urb-LUC0	134	0.134	0.049	0.054	0.066	0.069	4	0.03	0.37
Urban >60%	Urb-LUC0-BCP1	37	0.202	0.118	0.149	0.184	0.178	6	0.16	0.83
Urban >60%	Urb-LUC1	168	0.177	0.096	0.105	0.114	0.114	6	0.04	0.61
Urban >60%	Urb-LUC2	121	0.191	0.060	0.087	0.059	0.080	4	0.03	0.48
Urban >60%	Urb-LUC3	38	0.165	0.093	0.097	0.088	0.109	2	0.05	0.55

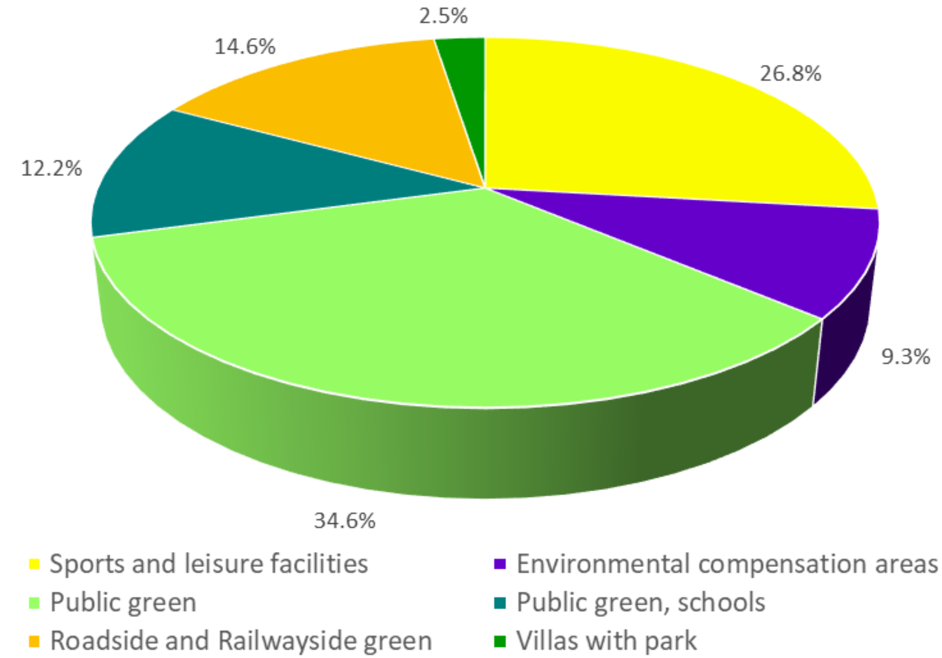
SMU ESs synergies and trade-offs



Contribution of each SMU to ESs provision

6. Soil Ecosystem Services

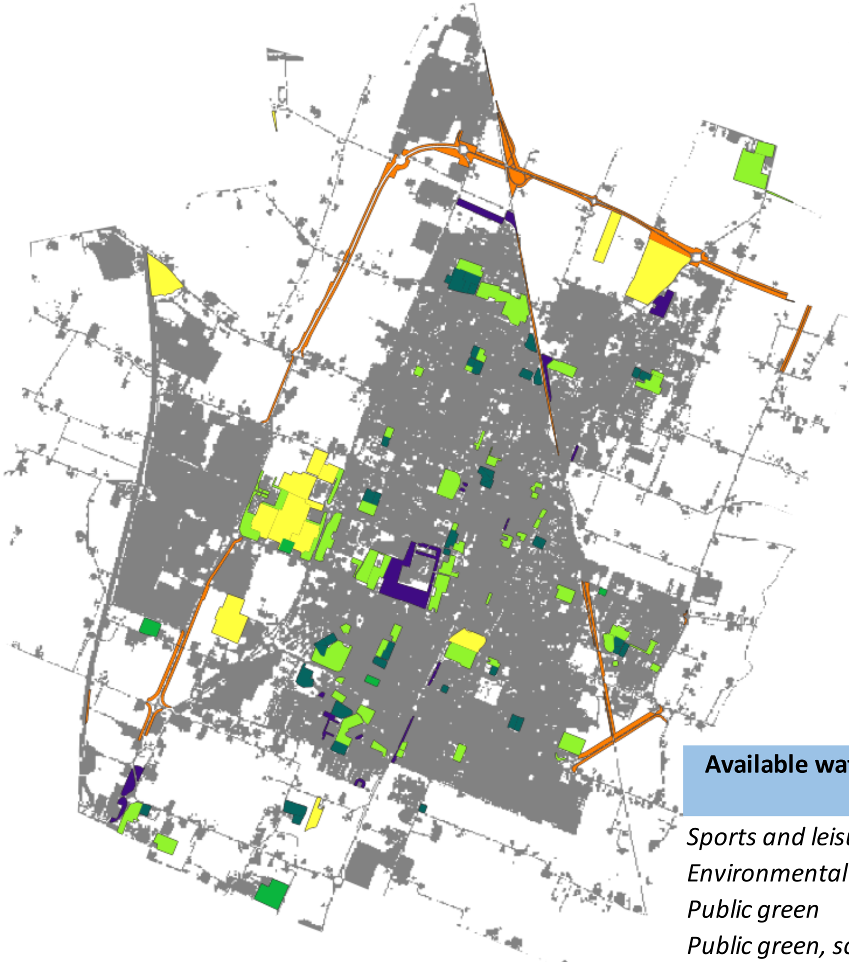


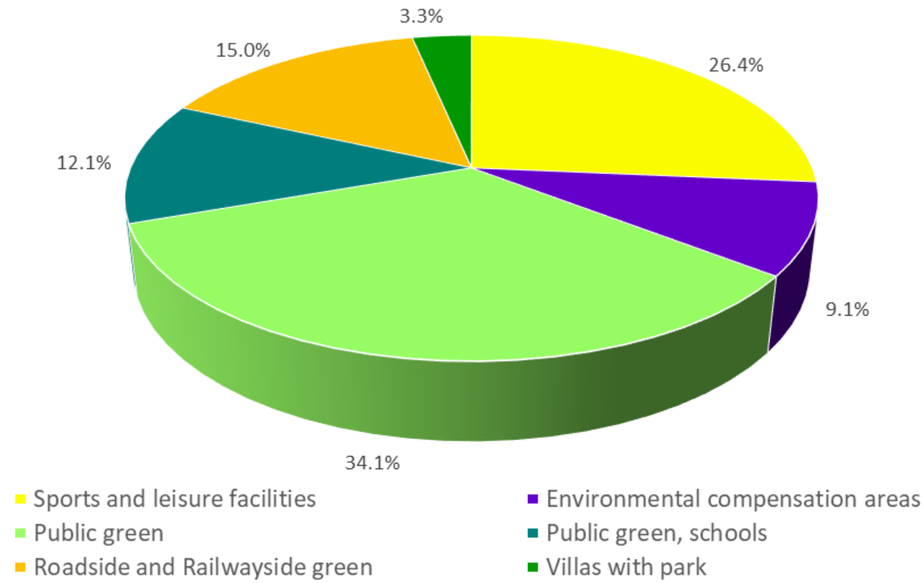


Green areas C stock 0-30 cm	Cstock Mg	Area Ha	Cstock Mg/ha	C stock/ab Mg	CO2eq Mg	CO2 eq /ab Mg
Sports and leisure facilities	4041	51.2	78.9	0.06	14819	0.21
Environmental compensation areas	1407	16.9	83.2	0.02	5158	0.07
Public green	5212	64.7	80.6	0.07	19112	0.27
Public green, schools	1832	22.6	81.2	0.03	6719	0.09
Roadside and Railwayside green	2195	31.5	69.6	0.03	8049	0.11
Villas with park	379	6.4	59.4	0.01	1388	0.02
Total	15067	193.2	78.0	0.21	55246	0.78

Cropland avg = 43.4 Mg C ha^{-1}

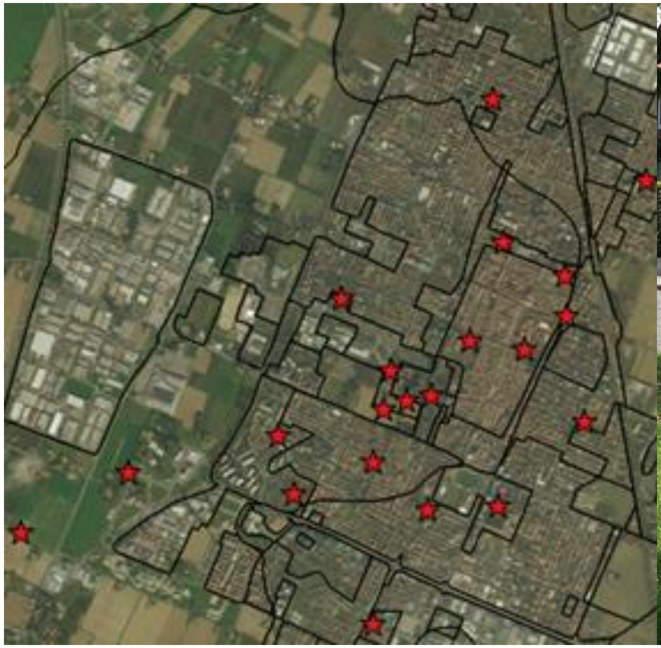
6. Soil Ecosystem Services

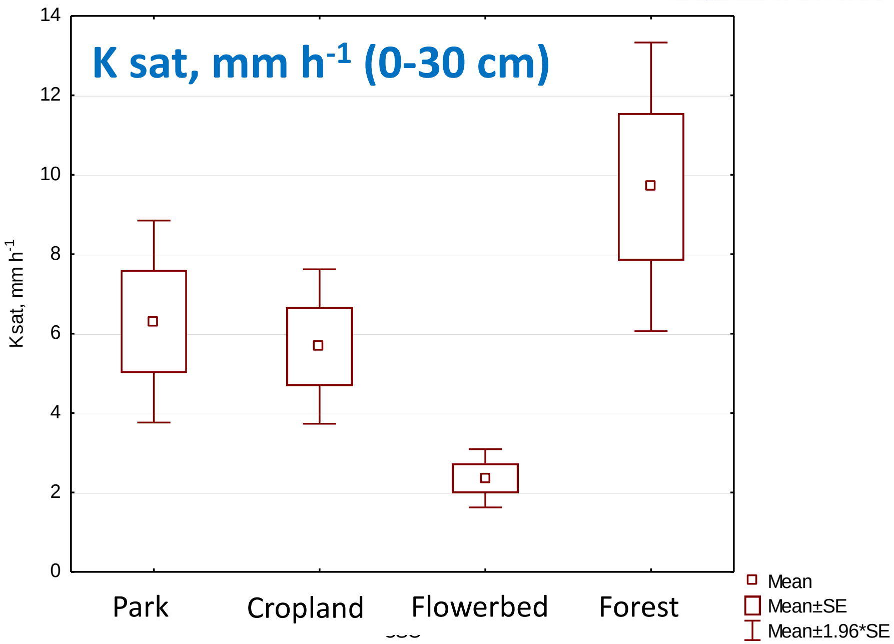




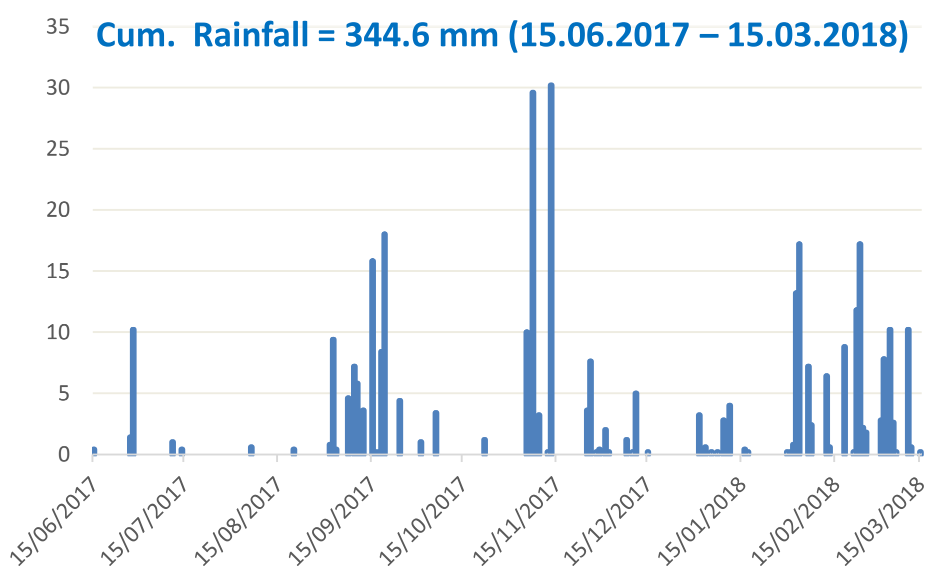
Available water storage capacity	Area Ha	AWC m3	AWC m3/ha	AWC m3/ab	AWC m3/tree	mm/m2
Sports and leisure facilities	51.2	15488	302.4	0.218	0.456	30.2
Environmental compensation areas	16.9	5324	315.0	0.075	0.157	31.5
Public green	64.7	20024	309.6	0.282	0.589	31.0
Public green, schools	22.6	7124	315.8	0.100	0.210	31.6
Roadside and Railwayside green	31.5	8790	278.9	0.124	0.259	27.9
Villas with park	6.4	1934	303.3	0.027	0.057	30.3
Total	193.2	58682.0	303.7	0.826	1.726	30.4

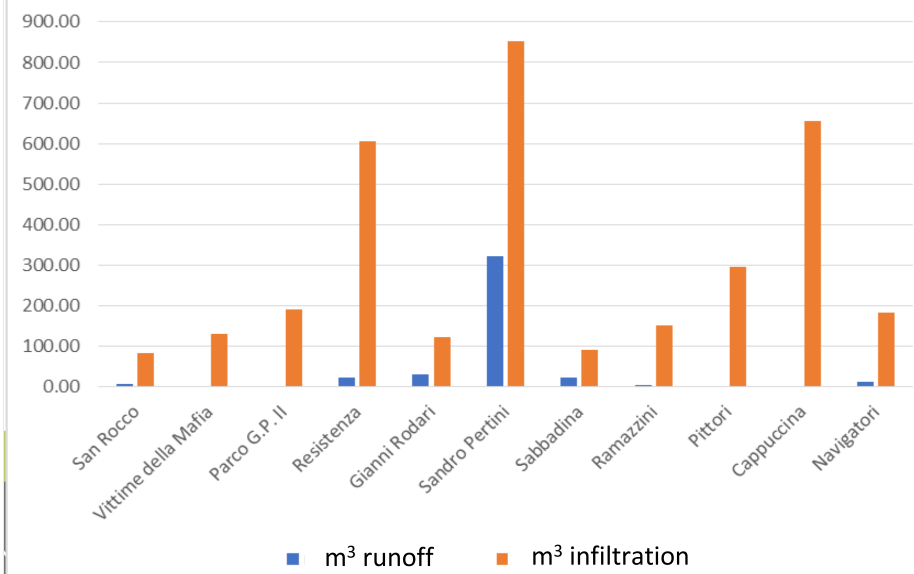
6. Soil Ecosystem Services



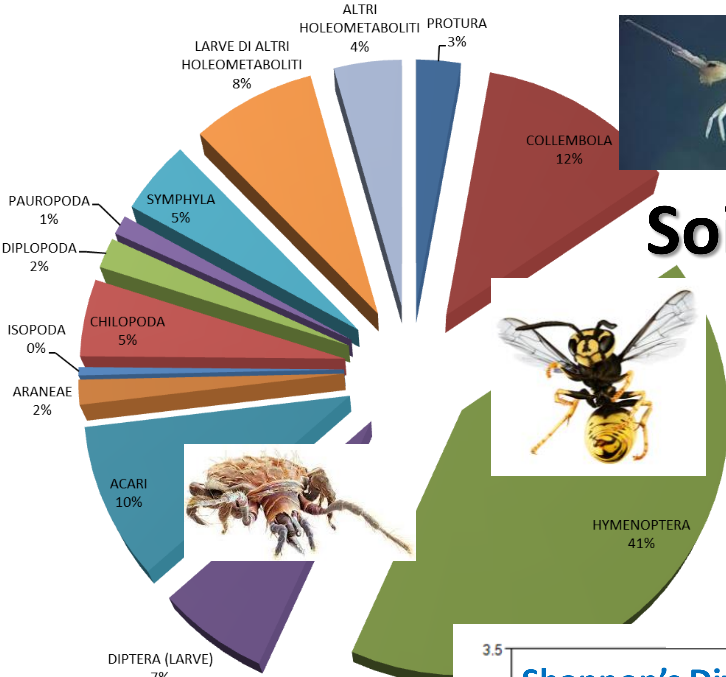


Water Cycle Regulation Park area = 10 ha Infiltration = 33,574.3 m^3 (ca. 90% cum. precip.)



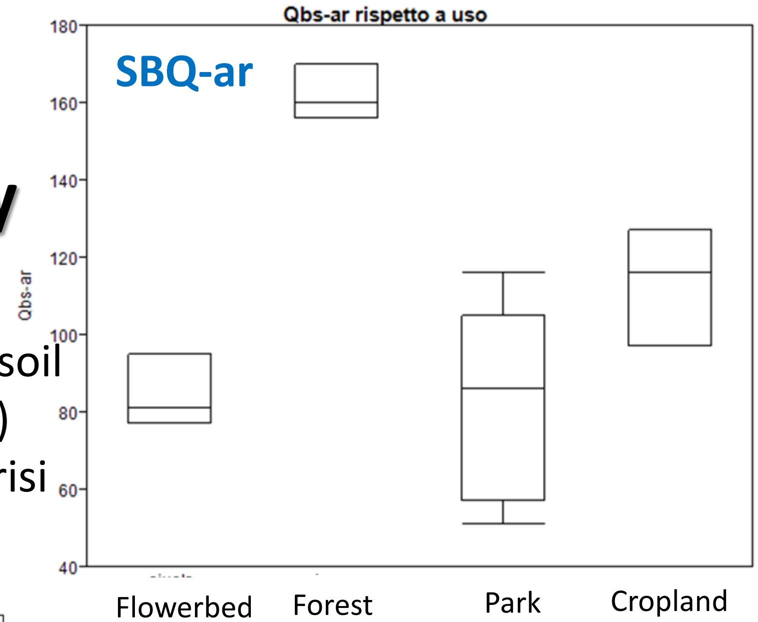


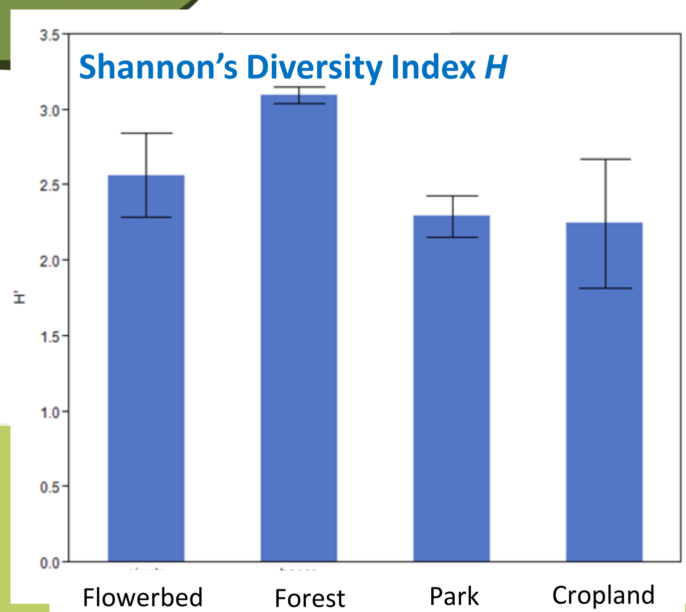
6. Soil Ecosystem Services

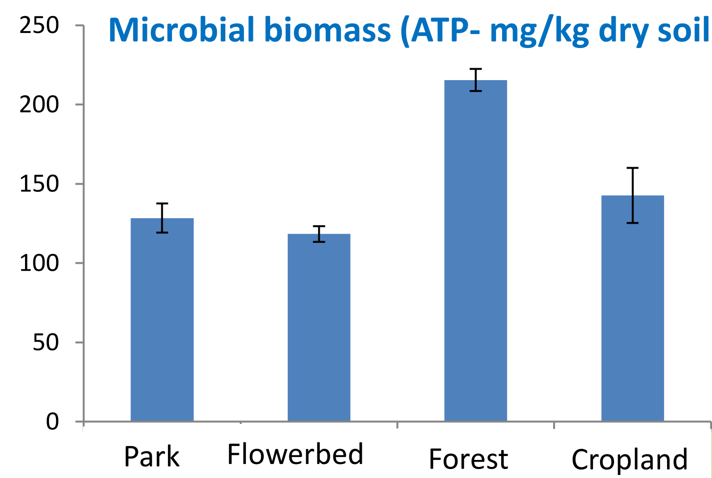


Soil biodiversity

SBQ is given by the eco-morphology of soil meso-fauna (<2mm) and its quantity (Parisi et al., 2001)





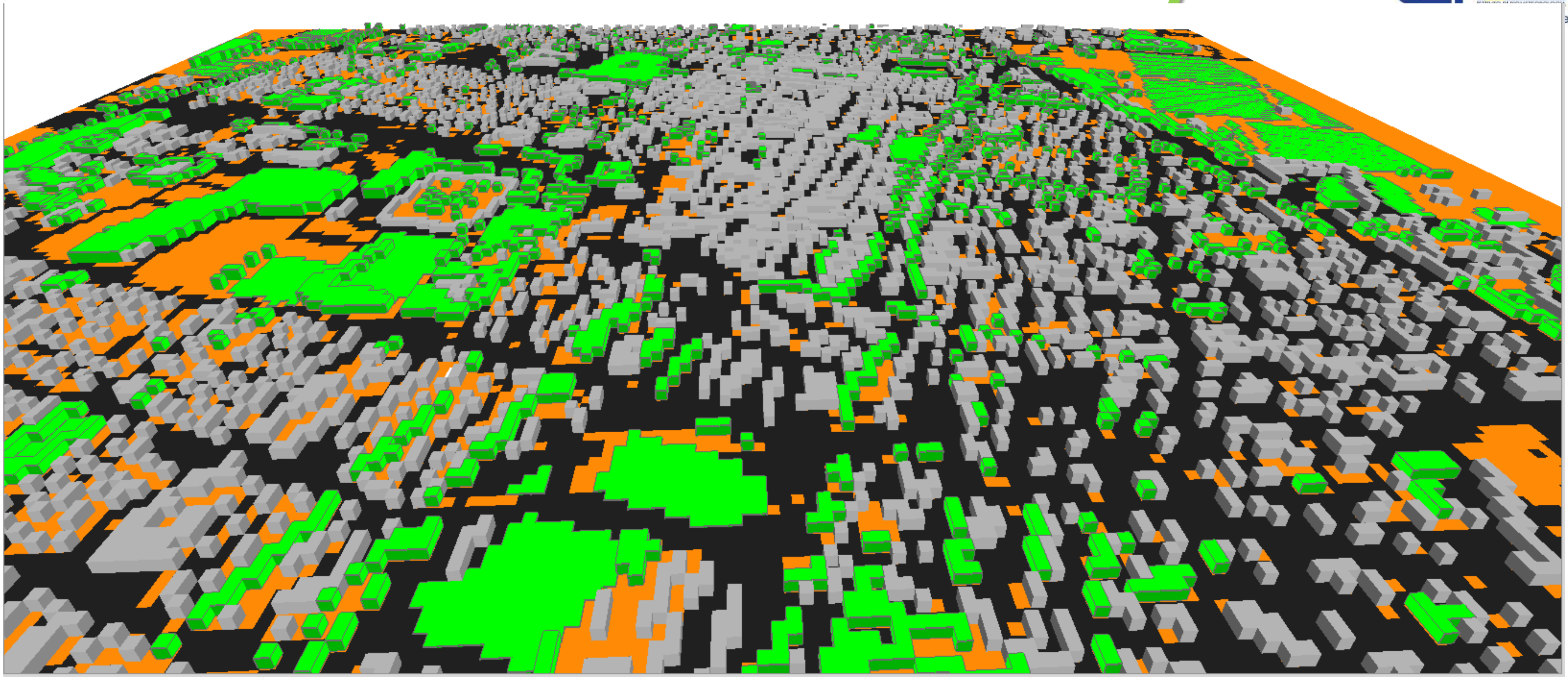


7. Microclimate analysis

The **Envi-met microclimatic model** was set up for the whole Carpi city in order to understand the urban microclimatology under hot days conditions.

Input data are recorded (every 30 minutes) at the SOS4Life meteo-station in Carpi

7. Microclimate analysis



Bare Ground
Asphalt
Vegetation
Building

Land use of Carpi as parameterized in the Envi-Met Model

METEO DATA

Wind speed: 2.5 m/s ---- 80°Nord

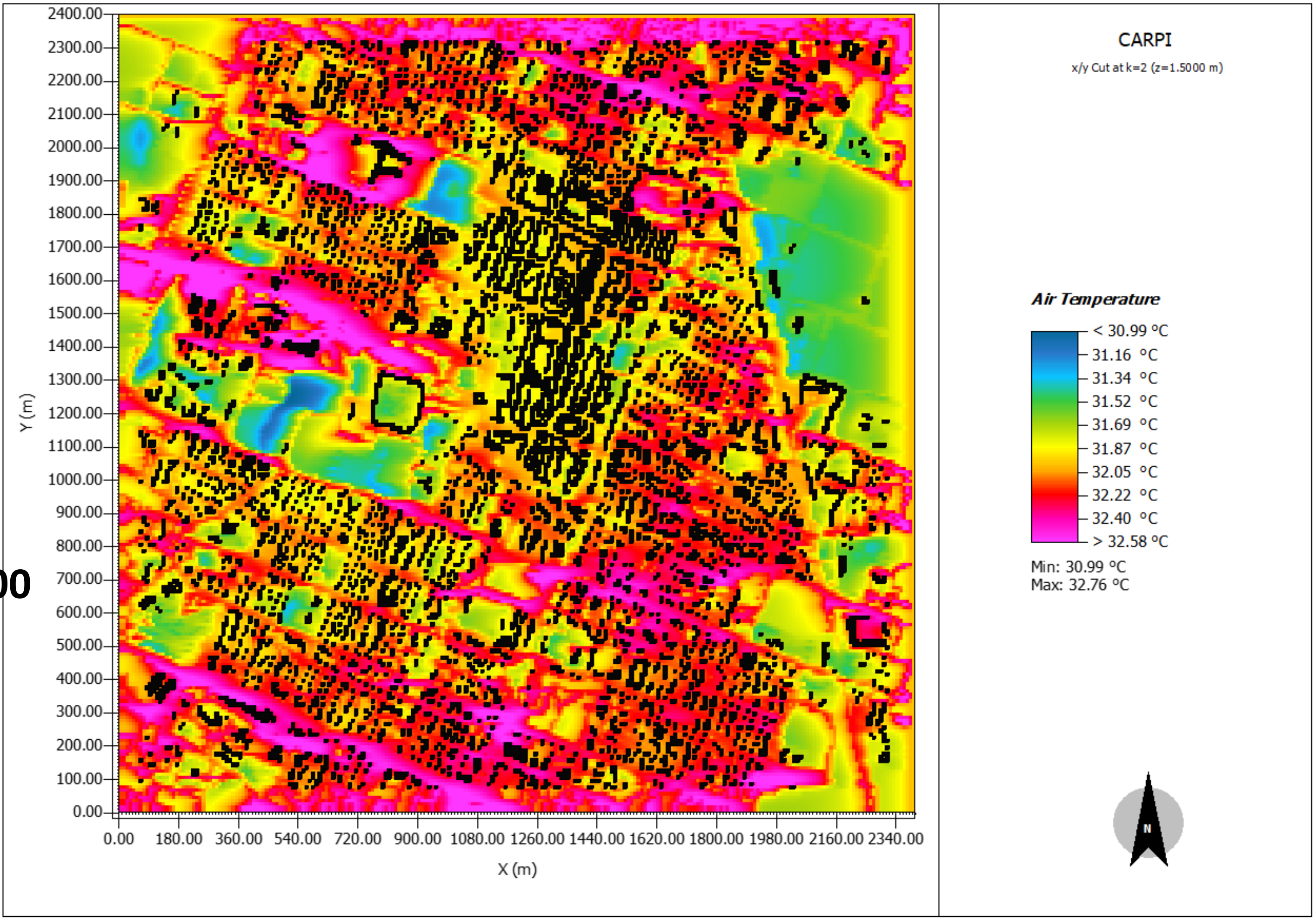
Air Temperature: max=35.4°C min=21.1°C

Relative Humidity: max=90% min=42%

7. Microclimate analysis

Areas with higher surface temperature (fuchsia) are clearly distinguished from those with lower temperature (green/blue). It is clear how parks and vegetated areas in general are a “cold well” for the city and the importance that they have in the microclimatology of the urban environment. The fuchsia zones are the most overheated ones due to the non-permeable surface (mainly asphalt) and from map it is possible to identify priority areas to intervene to mitigate the “heat island” effect.

Air Temperature @ 12:00

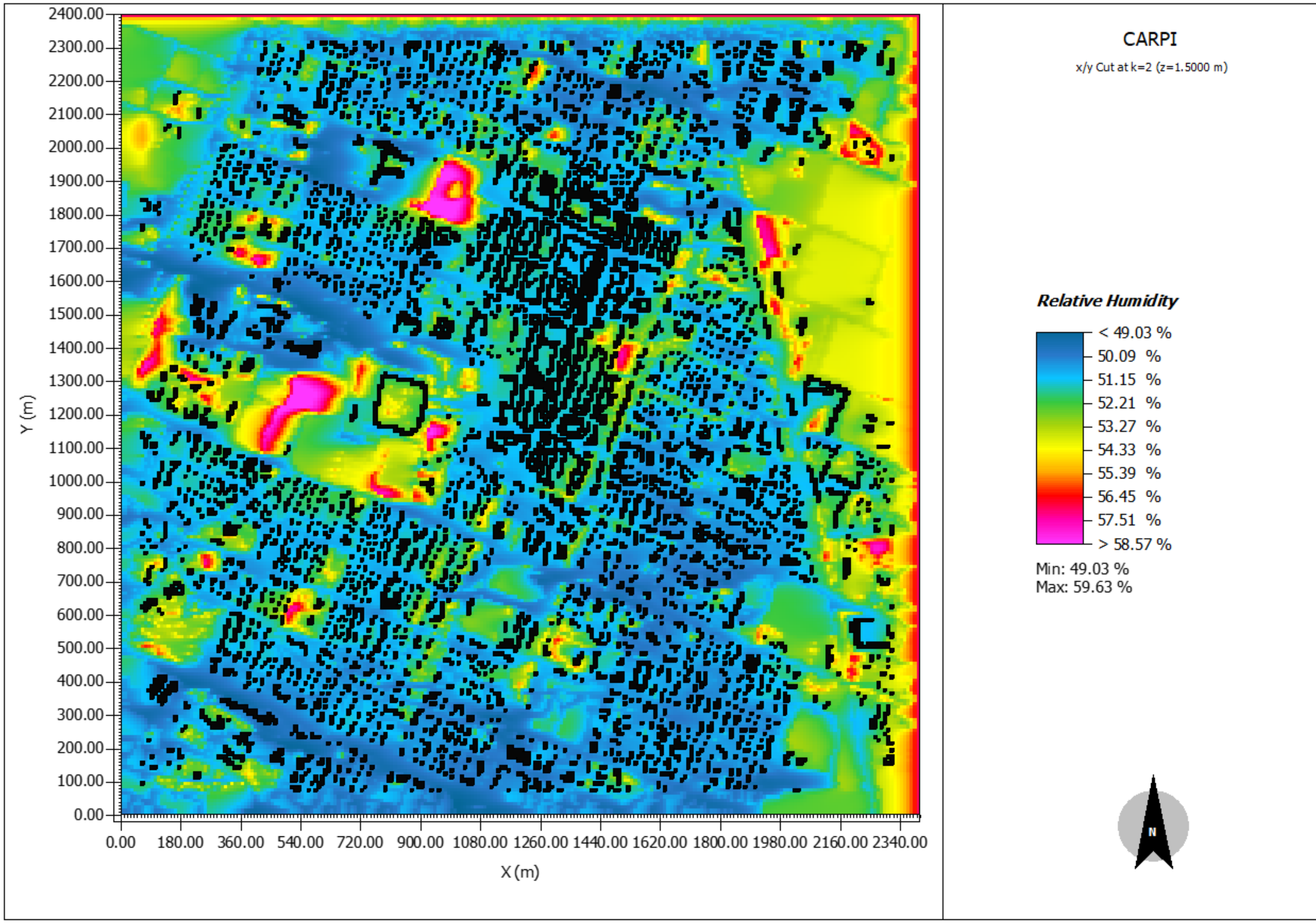


SOS4LIFE
SAVE OUR SOIL FOR LIFE

7. Microclimate analysis

Vegetated areas are characterised by higher relative humidity and are almost coincident wih parks; the increase in relative humidity results in a lower air temperature for the same areas.

Relative Humidity @12:00



RegioneEmilia-Romagna

Consiglio Nazionale delle Ricerche

SOS4LIFE
SAVE OUR SOIL FOR LIFE

Conclusions. I

The presented methodology

- Allows to assess and compare the impact of soil sealing in term of reduction/loss of the ecosystem services provided by urban soils under different management options;
- Allows to compare the loss of services with the gains resulting from the realization of new infrastructures and services;
- Provides assessment tools to support land planning (i.e. maps) to the aim to reduce/compensate soil sealing taking explicitly into account local land resources and the functions of different soils;
- Highlights the multifunctional role played by soils in the urban environment and the relevance of the services provided to the citizens.

Conclusions. II

- Urban soils have characteristics and properties similar to those of agricultural soils in the peri-urban areas, and result from less or more intense disturbance of in situ soils with or without addition of soil materials from nearby areas;
- The degree of disturbance is highly variable and depends from the size of the green areas, their use (vegetation cover) and past/current management; as a consequence, these affect the properties of soils of urban areas and their capacity to sustain the deliver of ESs;
- The inherent complexity of the urban soil environment requires *ad hoc* survey to properly quantify the contribution of soil ecosistem services and to identify potential disservices due to mis-use/-management;
- Sustainable urban environment requires more interactions and cooperation between urban planners and soil/climate/vegetation experts.

Thanks for your attention

www.sos4life.it

SAVE OUR SOIL FOR LIFE

World Forum on Urban Forests Mantova 2018