Hydrological characteristics of degraded soils of a landfill in Northern Italy: a comparison between instrumental data and predictive models

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The increase in human activities in recent decades has resulted in an ongoing depletion of soil resources to the point that the relevant authorities have included in their priorities the recovery of degraded areas.
A Life+ project Life 10 ENV/IT/0400 New Life, **http://www.lifeplusecosistemi.eu** includes, among its objectives, the environmental restoration of a degraded area near Piacenza (Italy). This innovative reconstitution method improves degraded soils through a controlled incorporation of organic matter by means of mechanical and chemical processes that originate neoaggregates of soil. The area of Life+ project from 1972 to 1985 was a landfill area then covered with a layer of soils of various kinds, on average 50 cm thick, left to be colonized by spontaneous plant species. Since 2005 there have been some modifications involving the planting of trees and shrubs, which have had little success except in some areas.
The results of physico-chemical analysis of sample soils and the vegetation ecological study of this area show the soil degradation.
The lower capacity to make water available for the components of the ecosystem is a characteristics of a degraded soil so it is important to study their hydrological characteristics.
In this work we study the hydrological characteristics of the 11 sample soil representative of the study area and we assess whether predictive systems in use today (PTFs) are suitable for predicting them.

PTFs: mathemathical models which correlate the water retention and hydraulic conductivity with some easily-measurable chemical and physical properties of the soil such as texture, density, porosity, and organic carbon content.
These 18 PTFs used are based on databases of soils distributed worldwide following two models: Brooks and Corey (1964) and van Genuchten (1980); the program SPAW (Soil-Plant-Air-Water) has also been used.
The processing of the PTFs was performed using the program CalcPTF 3.0, the database HYPRES and the program SPAW. The goodness of the PTFs was calculated through the root mean square error (RMSE) test.
The hydrological data of the landfill cover soils obtained through PTFs were also compared with theoretical water retention curves of a hypothetical control soil.

sample	sand	clay	silt	pH	tot C	O.C.	tot N	C/N	HA+FA	$CaCO_3$	salinity	CSC	IRS	depth
	g/kg	g/kg	g/kg		%	%	%		g/kg	%	µs/cm	meq/100ml		cm
1	219	123	658	7,87	3,36	1,94	0,60	14,46	0,94	13,0	197	16,96	76,90	55
2	179	125	696	7,91	5,80	4,13	0,41	12,77	0,87	14,7	212	34,27	46,00	30
3	279	123	598	8,10	5,62	4,14	0,20	16,25	1,18	19,0	151	7,19	65,13	60
4	115	147	738	7,95	2,28	1,67	0,28	10,92	1,01	3,8	232	20,92	102,21	30
5	122	124	754	8,25	2,42	1,04	0,30	18,79	1,05	13,4	167	19,08	97,42	62
6	103	147	750	7,78	1,78	1,35	0,11	10,08	0,90	5,7	196	27,29	40,68	32
7	333	125	542	8,42	3,83	1,92	0,75	21,86	0,82	22,9	130	22,57	128,73	45
8	167	168	665	7,90	6,26	4,10	0,18	13,63	0,94	26,6	288	23,67	43,78	47
9	250	123	627	8,06	3,78	2,35	0,22	14,50	0,93	13,8	252	32,22	99,45	47
10	180	98	722	8,04	3,72	2,68	0,19	11,39	1,07	5,9	136	31,80	71,45	50
11	178	123	699	7,96	4,90	3,63	0,39	13,85	1,03	12,8	248	34,10	75,68	40

sample	texture	b.d.*	p.d.*	O.C.	depth	structure
		g/cm^3	g/cm^3	%	cm	
hypothetical soil	silty loam	1,4	2,6	1	100	good
mean of landfill soils	silty loam	1,4	2,6	2,6	45	compacted

* b.d. = bulk density; p.d. = particle density

sample	pressure (-KPa)							
	0,10	0,25	1,00	3,16	6,31	10,00	31,62	1496,24
1	38,04	33,52	30,16	28,64	27,60	26,57	21,23	18,97
2	37,50	34,05	31,58	29,71	28,93	28,44	21,89	21,47
3	36,75	34,70	32,18	28,46	26,77	26,02	19,78	10,44
4	38,01	35,29	31,08	27,28	25,21	23,95	17,63	17,17
5	33,92	32,13	28,70	25,44	24,00	23,08	16,71	14,55
6	36,51	34,66	32,00	29,29	27,71	26,81	19,45	11,22
7	34,27	31,52	29,48	25,58	23,82	22,68	14,90	8,35
8	35,10	34,73	34,01	33,43	32,85	32,54	28,47	20,38
9	39,24	36,70	32,89	28,75	25,83	23,50	17,90	16,03
10	41,87	40,31	36,78	31,84	29,53	27,06	20,06	10,79
11	40,12	33,80	30,40	29,16	28,67	28,29	22,38	19,76

volumetric water content (θ%)

PTF	region	model
HYPRES	Europe	VG
Saxton et al., 1986	USA, nationwide	BC
Campbell and Shiosawa, 1992	No particular	BC
Rawls and Brakensiek, 1985	USA, nationwide	BC
Williams et al., 1992	Australia	BC
Williams et al., 1992	Australia	BC
Oosterveld and Chang, 1980	Canada, Alberta	BC
Mayr and Jarvice, 1999	UK	BC
Wösten et al., 1999	Europe	VG
Varallyay et al., 1982	Hungary	VG
Vereecken et al., 1989	Belgium	VG
Wösten et al., 1999	Europe	VG
Tomasella and Hodnett, 1998	Brazil	VG
Rawls et al. 1982b*	USA, nationwide	VG
Gupta and Larson, 1979	Central USA	VG
Rajkai and Varallyay, 1992	Hungary	VG
Rawls et al. 1983*	USA, nationwide	VG

* = corrected for OM according to Nemes et al., 2009

The van Genuchten (1980) water retention equation:

$$\frac{q - q_r}{q_s - q_r} = \frac{1}{\left[1 + (ah)^n\right]^m}$$

The Brooks and Corey (1964) model:

$$\frac{q - q_r}{f - q_r} = \begin{cases} \left(\frac{h_b}{h}\right)^l, & h > h_b; \\ 1, & h \le h_b \end{cases}$$

θ = volumetric soil water content ($cm^3\ cm^{-3}$);
θ_r= residual soil water content ($cm^3\ cm^{-3}$);
θ_s = saturated soil water content, ($cm^3\ cm^{-3}$);
ϕ = soil porosity, ($cm^3\ cm^{-3}$);
λ = pore size distribution index (dimensionless);
h = capillary pressure (cm);
h_b = air-entry pressure (cm);
α = parameter of the van Genuchten equation corresponding approximately to the inverse of the air-entry value, (cm^{-1});
m, n = empirical shape-defining parameters in the van Genuchten equation, (dimensionless).

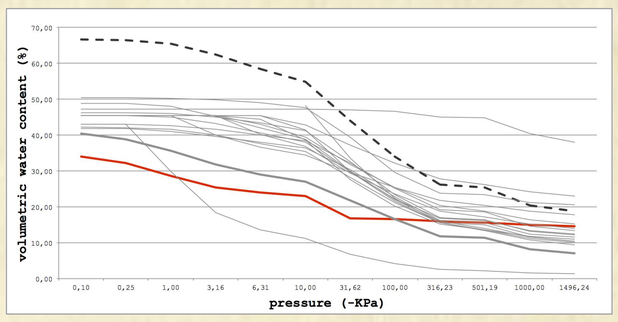
$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(q_i - q_i^*)^2}$$

N = number of measurements;
θ_i and θ_i^* = real and estimated volumetric water content contenuti (θ%).

PTF	RMSE (%)										
	1	2	3	4	5	6	7	8	9	10	11
HYPRES	12,8	12,3	13	14,2	15,9	13	15,2	7	12,6	9,7	12,2
Saxton et al., 1986	12,6	12,3	11,6	14,1	15,7	12,6	13,8	17,1	12,2	10,2	12,3
Campbell and Shiosawa, 1992	13,1	12,6	13,1	15,6	17	14,8	15,6	10,3	13,4	11,3	12,6
Rawls and Brakensiek, 1985	11,5	11,3	10,5	13,5	14,9	12,2	12,7	17,8	10,9	8,4	11,3
Williams et al., 1992	9,7	9,1	9,7	11,1	12,6	10,3	12,5	6,1	9,6	6,4	9,1
Williams et al., 1992	11	11,7	11,4	12,5	14,1	11,3	11,8	11,3	10,6	8,5	11,4
Oosterveld and Chang, 1980	11,6	10,9	10,9	13,6	15,2	12,5	12,9	12,9	11	8,3	10,9
Mayr and Jarvice, 1999	12,2	13,3	10,5	10,4	9,8	11	9,1	22,3	10,5	11,3	12,8
Wösten et al., 1999	8,9	5,4	9	10,4	13,1	10,2	12,1	7,1	9	6,3	8,2
Varallyay et al., 1982	5,2	5,7	3	5,6	6,1	3,8	5,7	10,5	4,1	2,5	5,3
Vereecken et al., 1989	8,5	8,6	8,4	12	11,6	10,7	10,7	5	8,5	3,3	8,1
Wösten et al., 1999	8,5	8,3	8,8	9,9	11,3	8,5	10,5	5,2	8,5	6,2	8,2
Tomasella and Hodnett, 1998	24,8	26,9	23,4	29,6	31,5	29,1	22,7	15,9	23,5	24,3	26,6
Rawls et al. 1982b*	13,2	16,1	15,8	15,4	15,8	13,7	14,8	10	13,6	11,8	15,2
Gupta and Larson, 1979	16,2	17,6	16,6	19,6	20,8	18,7	17,2	10,1	16,1	15,2	17,3
Rajkai and Varallyay, 1992	18,9	15,9	17,1	19,3	21,8	18,5	20	11,3	18,5	18,9	16,7
Rawls et al. 1983*	11,3	12,5	12,7	13,2	14	11,7	13,1	7	11,5	9,2	12,1

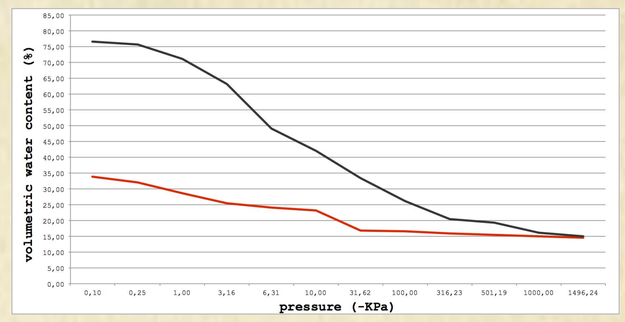
* = corrected for OM according to Nemes et al., 2009

real (red) and estimated (gray) water retention curves



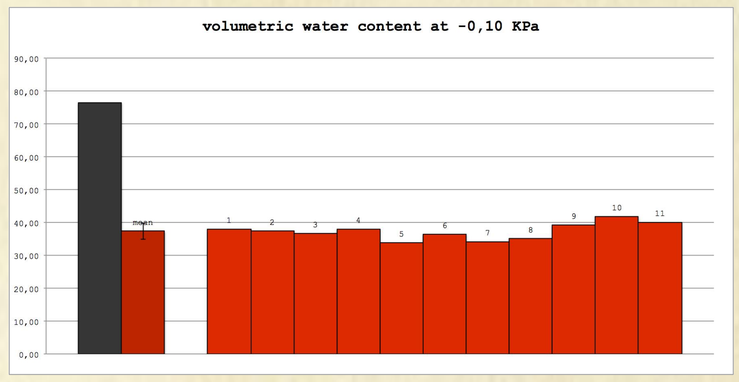
real (red) and hypothetical (gray) water retention curves*

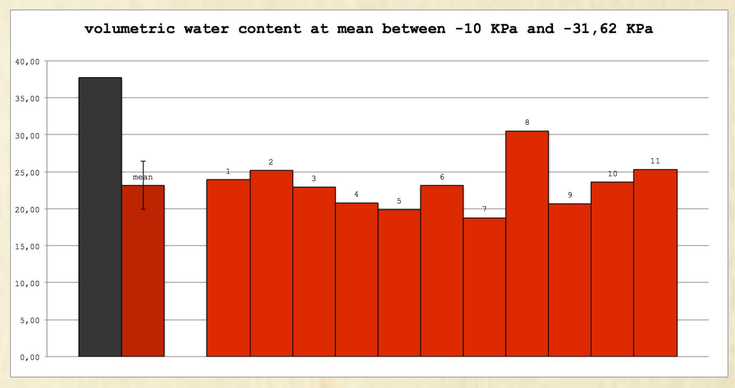
*(*hypothetical = mean of estimated values for an hypothetical soil)*

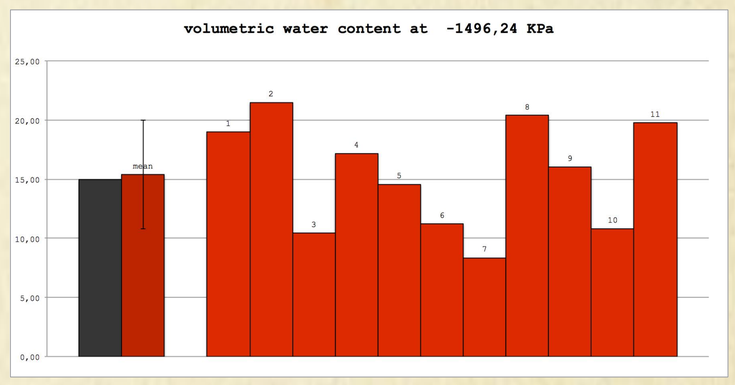


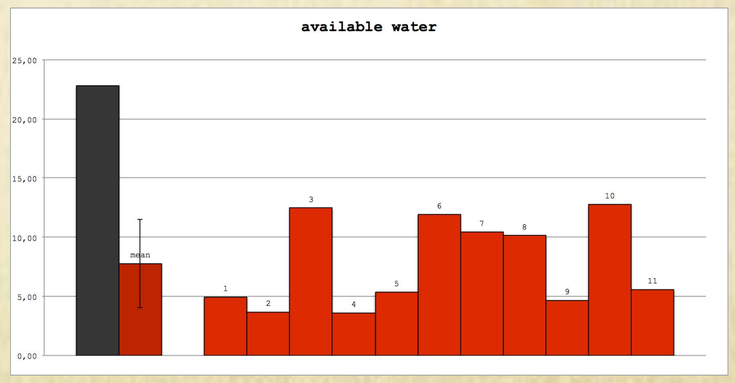
In the figure they are shown the 18 water retention curves related to sample number 5 developed starting from the PTFs compared with the real one; the best (Varallyay et al. (1982)) and the worst (Tomasella and Hodnett (1998)) curves are highlighted as the outcome of the RMSE test. The different valuesof θ% obtained instrumentally were processed through a comparison with the average of the values obtained from processing PTFs. The comparison between the actual data and the average of those predicted reveals that the curve is similar but the PTFs data always overestimate the real data for all pressure values lower than - 31,62 KPa, whereas for pressure values of -1496.24 KPa in 5 samples the real datum is higher than the estimated one, in the same number of cases it is lower, while in one case it is equal.
The other figure showes the comparison between real (sample 5) and hypothetical water retention curves.

The water content at different pressure values for all the soils sampled in comparison with the hypothetical control soil









The vegetation of the area is predominantly represented by Therophytes (44%)(ephemeral annual species) that complete their life cycle before the adverse season (dry summer). This vegetation belonge to the phytosociological class *Stellarietea mediae* which includes nitrophilous annual vegetation of disturbed areas.

Conclusions
From the study of the hydrological characteristics of landfill cover soils it has emerged that these have less available water compared to a hypothetical soil with less organic carbon content; this represents an aspect of degradation. The low water content, together with the lack of depth and compacted structure of soils, would justify the current presence of a vegetation cover which consists predominantly of therophytes instead of a more developed and stable perennial vegetation with shrubs and trees, as observed for other landfills several years after their coverage.

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