Small-scale spatial variability of Technosol properties in a chronosequence of reclamation of dredged sediment landfills

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Abstract

Active reclamation is often necessary to ensure a transformation of mining waste into Technosols -"soils dominated or strongly influenced by human made material" - and restore its utility and environmental value. The objective of this study was to assess the spatial variation of the physicochemical properties of a Technosol forming on dredged sediment landfills left by alluvial gold mining in a chronosequence of reclamation (0, 4, 8 and 12 years). We hypothesized a higher spatial dependency of most soil properties with increasing time of Technosol formation and an overall homogenization of the soil resulting from pedogenetic processes. Our results showed that most of the investigated physical and chemical properties changed significantly among Technosols of different ages. The content of organic matter, phosphorus, and exchangeable cations showed the highest spatial variability in Technosols of all ages. In older Technosols, most soil properties showed less spatial variability than in younger Technosols. A multivariate geostatistical assessment allowed the delineation of spatial clusters i.e. homogeneous zones with distinctive physicochemical properties within areas of the chronosequence. This spatial clustering showed that reclamation and Technosol formation led to spatially-dependent fragmentation processes reflected in more and smaller homogeneous zones in the oldest Technosol assessed in the chronosequence. From the perspective of reclamation management, understanding the spatial variability of highly heterogeneous Technosols where substantial changes can be observed within small distances can support the development of reclamation strategies suitable to the characteristics of each field as well as the determination of its potential uses.

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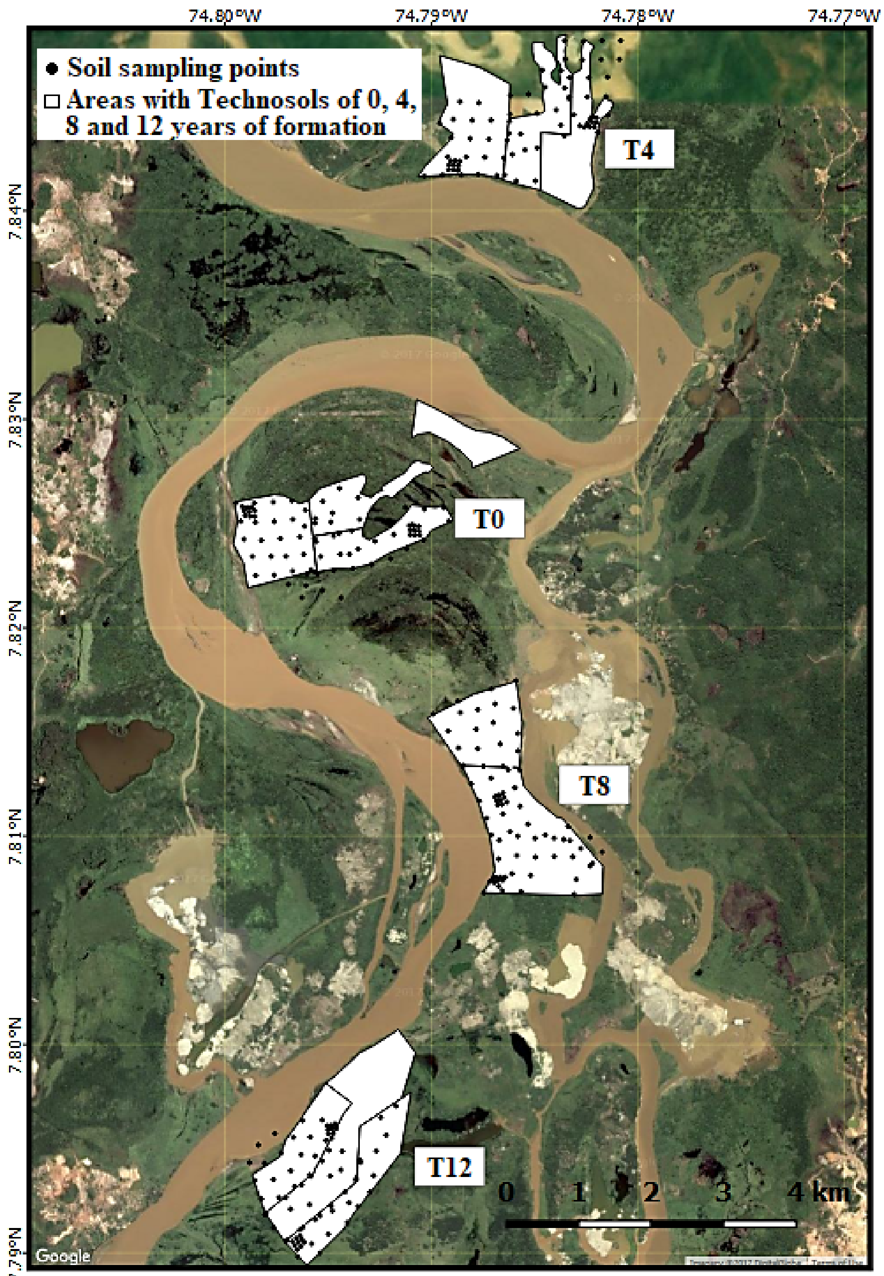
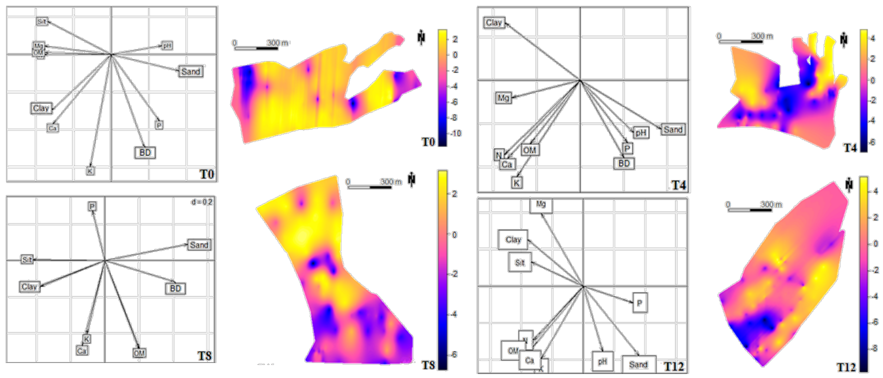
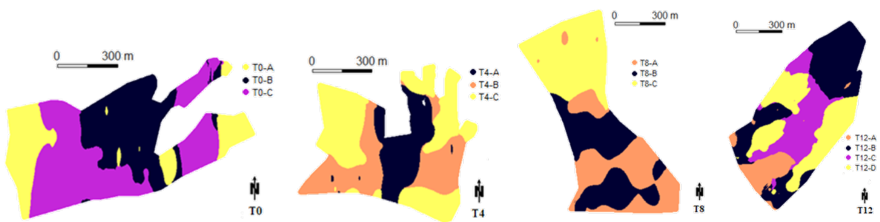


74.80°W
74.79°W
74.78°W
74.77°W
7.84°N
7.83°N
7.82°N
7.81°N
7.80°N
7.79°N
Soil sampling points
Areas with Technosols of 0, 4, 8 and 12 years of formation
T4
T0
T8
T12
0 1 2 3 4 km
Google





		Descriptive statistics				Univariate geostatistical model							Model performance			Global Moran's I	
Variable[a]	**Plot**	**Median**	**SD**	**Skewness**	**Kurtosis**	**Model**[b]	τ^2	σ^2	$\phi(m)$	**NSR**	ψ_A	ψ_R	**ME**[c]	**MSE**	**RMSE**	**Index**	p
pH	**T0**	5.30	0.5	0.25	0.03	Mat	0.14	0.09	200	2	0.00	2.54	0.004	0.005	0.42	0.32	0.000
	T4	5.10	0.5	-0.11	-0.19	Gau	0.23	0.02	100	12	0.00	1.00	0.001	0.001	0.52	0.14	0.030
	T8	5.00	0.5	0.05	-0.19											0.16	0.020
	T12	4.90	0.4	-0.19	-0.38	Sph	0.12	0.09	525	1	0.00	10.69	0.000	0.000	0.41	0.04	0.250
N	**T0**	0.31	0.1	1.52	1.00	Exp	0.00	0.01	173	0	0.00	1.00	0.001	0.010	0.09	0.58	0.000
	T4	0.20	0.2	0.73	-0.16	PW	0.01	0.01	100	1	0.00	1.55	0.001	0.006	0.56	0.51	0.000
	T8	0.16	0.1	0.42	-0.97	Exp	0.00	0.02	352	0	0.01	1.00	0.000	0.004	0.07	0.66	0.000
	T12	0.21	0.1	0.47	-0.67	Sph	0.01	0.01	178	2	0.83	6.85	0.000	0.000	0.12	0.19	0.008
OM	**T0**	7.11	3.9	1.57	1.10	Exp	5.09	12.00	262	0	0.00	1.00	0.001	0.000	2.79	0.59	0.000
	T4	4.22	4.6	0.93	0.25	PW	1.38	2.31	100	1	0.00	1.00	0.030	0.009	1.57	0.49	0.000
	T8	3.35	3.0	0.57	-0.70	Exp	1.20	9.79	308	0	0.00	1.00	0.014	0.004	1.91	0.65	0.000
	T12	4.53	3.7	0.71	-0.17	Sph	10.00	2.74	201	4	0.82	6.25	0.000	0.000	3.45	0.20	0.005
P	**T0**	13.00	7.1	0.88	3.58											0.44	0.000
	T4	16.00	7.8	0.04	-0.45	Sph	14.00	34.32	166	0	0.01	1.00	0.160	0.012	6.18	0.43	0.000
	T8	18.00	12.2	0.41	-0.81	Sph	38.00	126.60	575	0	0.00	1.00	0.043	0.002	8.06	0.57	0.000
	T12	11.00	8.0	0.69	0.45	Sph	20.00	44.02	769	0	0.84	2.21	0.014	0.001	6.19	0.29	0.000
K	**T0**	0.09	0.1	1.61	3.78	Cub	0.15	0.25	383	1	0.00	1.07	0.000	0.024	0.07	0.27	0.000
	T4	0.20	0.1	0.83	0.22	Sph	0.09	0.01	100	9	0.00	1.00	0.000	0.003	0.11	0.30	0.000
	T8	0.20	0.1	0.97	1.04	Sph	0.00	0.01	129	0	0.00	1.00	0.000	0.004	0.10	0.36	0.000
	T12	0.15	0.1	0.56	-0.57	Sph	0.01	0.01	200	2	0.86	4.61	0.001	0.006	0.11	0.00	0.420
Ca	**T0**	2.46	2.2	1.31	1.10	Exp	0.00	4.83	163		0.38	3.15	0.019	0.007	1.88	0.27	0.000
	T4	3.16	2.4	0.62	-0.53	Cub	2.53	2.61	364	1	0.00	2.04	0.013	0.003	1.77	0.42	0.000
	T8	2.48	1.5	0.74	0.42	Sph	0.50	1.03	202	0	0.00	1.00	0.016	0.002	1.14	0.36	0.000
	T12	2.56	1.9	1.28	1.66	Sph	1.00	1.22	119	1	0.32	1.00	0.005	0.002	1.70	0.19	0.005
Mg	**T0**	0.37	1.1	1.68	2.07	Sph	0.36	0.58	203	1	0.00	11.86	0.006	0.880	1.03	0.27	0.000
	T4	1.68	1.0	0.07	-1.21	Sph	0.71	0.38	340	2	0.00	1.57	0.007	0.004	0.89	0.38	0.000
	T8	1.00	0.9	1.49	2.33	Sph	0.60	0.05	200	12	0.00	1.15	0.001	0.000	0.78	0.27	0.000
	T12	1.33	1.2	0.72	-0.55	Sph	0.60	0.88	527	1	0.00	1.00	0.010	0.005	0.94	0.35	0.000
Na	**T0**	0.19	0.2	0.94	-0.29											0.37	0.000
	T4	0.27	0.1	0.15	-0.35											0.11	0.073
	T8	0.15	0.1	2.14	7.34											0.24	0.001
	T12	0.15	0.1	1.38	1.76											0.30	0.000
Sand	**T0**	90.00	26.2	-1.08	-0.39	Sph	0.02	0.06	567	0	0.00	10.50	0.000	0.000	0.18	0.62	0.000
	T4	54.00	27.4	0.02	-1.43	Sph	0.01	0.05	197	0	0.70	2.00	0.008	0.014	0.21	0.47	0.000
	T8	78.00	22.7	-0.57	-0.91	Sph	0.04	0.70	353	0	0.00	1.00	0.000	0.001	0.20	0.29	0.000
	T12	74.00	25.3	-0.39	-1.42	Sph	0.00	0.07	483	0	0.00	1.00	0.004	0.018	0.18	0.56	0.000
Silt	**T0**	4.00	18.3	1.27	0.14	Mat	0.01	0.03	100	0	0.00	12.96	0.000	0.002	0.11	0.71	0.000
	T4	24.00	17.0	0.35	-0.74	Sph	0.07	0.21	103	0	0.69	2.06	0.007	0.020	0.13	0.52	0.000
	T8	12.00	15.8	0.69	-0.94	Sph	0.00	0.02	200	0	0.31	1.79	0.003	0.016	0.15	0.25	0.001
	T12	10.00	16.3	0.68	-0.83	Sph	0.00	0.04	746	0	0.91	3.72	0.002	0.012	0.12	0.52	0.000
Clay	**T0**	7.50	10.3	1.37	1.08	Sph	0.00	0.01	146	0	1.23	1.39	0.001	0.009	0.09	0.31	0.000
	T4	16.00	14.8	0.99	0.27	PW	0.01	0.00	174	2	0.83	1.00	0.000	0.000	0.12	0.27	0.000
	T8	7.00	11.3	2.43	7.67	Exp	0.00	0.01	36	0	0.00	1.00	0.000	0.004	0.10	0.19	0.005
	T12	10.00	12.6	1.11	0.37	Sph	0.00	0.01	158	0	0.16	1.25	0.001	0.008	0.10	0.34	0.000
BD	**T0**	0.96	0.2	0.48	-0.84	Cub	0.01	0.04	403	0	1.07	1.46	0.001	0.002	0.17	0.59	0.000
	T4	0.86	0.2	-0.08	1.51	Sph	0.00	0.02	119	0	0.16	2.70	0.000	0.002	0.14	0.04	0.280
	T8	0.89	0.2	0.00	-0.94	Exp	0.01	0.06	269	0	0.00	1.00	0.001	0.003	0.17	0.58	0.000
	T12	0.68	0.2	1.62	1.72	Sph	0.03	0.03	260	1	0.53	2.71	0.005	0.061	0.19	0.15	0.020
PR	**T0**	1.57	1.0	1.23	1.55	Gau	0.60	0.46	78	1	0.68	6.08	0.010	0.005	0.89	0.17	0.010
	T4	1.05	1.0	1.53	1.68					0						0.42	0.000
	T8	1.89	1.2	0.86	-0.49	Sph	0.90	0.34	200	3	0.00	1.00	0.001	0.001	1.13	0.18	0.009
	T12	1.37	1.4	0.72	-1.03	Mat	0.80	0.86	185	1	0.00	1.00	0.005	0.002	0.85	0.64	0.000

[a] OM, organic matter; BD: Bulk density, PR: Penetration resistance
[b] Sph: Spherical, Mat: Matern, Exp: Exponential, PW: Power exponential, Cub: Cubic, Gau: Gaussian
[c] ME: mean error, MSE: mean squared error, RMSE: root-mean-square error
[d] Missing values correspond to parameters for which spatial interpolation could not be conducted using ordinary kriging

Plot	**Zone**	**pH**	**N**	**OM**	**P**	**K**	**Ca**	**Mg**	**Sand**	**Silt**	**Clay**	**BD**	**PR**
T0	T0-A	5.05	0.43	11.23	5.81	0.11	3.78	1.40	50	32	17	0.85	1.78
	T0-B	5.45	0.32	7.56	15.11	0.18	2.94	0.51	85	7	11	1.21	1.89
	T0-C	5.48	0.31	7.29	12.69	0.04	1.25	0.36	89	5	5	0.95	1.65
T4	T4-A	4.96	0.42	14.04	15.74	0.32	6.02	2.25	51	19	19	0.88	
	T4-B	5.04	0.21	4.64	12.95	0.21	3.47	1.89	51	20	20	0.81	
	T4-C	5.35	0.12	2.63	18.77	0.17	2.27	1.03	76	9	16	0.95	
T8	T8-A		0.19	4.26	15.69	0.22	3.11	1.59	58	25	16	0.84	2.39
	T8-B		0.10	1.87	22.41	0.11	1.67	0.92	77	15	8	0.97	2.50
	T8-C		0.32	7.38	14.82	0.22	3.04	0.67	84	9	6	1.18	1.71
T12	T12-A	4.75	0.27	11.22	7.02	0.30	5.28	2.54	45	32	24	0.77	1.76
	T12-B	4.85	0.21	4.80	9.66	0.13	2.68	2.55	61	12	14	0.79	2.17
	T12-C	5.13	0.23	7.22	11.82	0.23	3.76	1.09	81	9	8	1.05	1.46
	T12-D	5.02	0.18	2.70	17.58	0.11	1.66	0.85	86	5	6	0.69	2.29

[a] OM, organic matter; BD: Bulk density, PR: Penetration resistance

[b] Missing values correspond to parameters for which spatial interpolation could not be conducted using ordinary kriging