Multi-indicator and geospatial based approaches for assessing variation of land quality in arid agroecosystems

Ahmed S. Abuzaid [a], Yasser, S.A. Mazrou [b,c] Ahmed. A. El Baroudy [d], Zheli Ding [e] and Mohamed. S. Shokr [d] *

[a] Soils and Water Department, Faculty of Agriculture, Benha University, Egypt;
[b] Applied College-Muhyle, King Khalid University, Saudi Arabia
[c] Department of Agriculture Economic, Faculty of Agriculture, Tanta University, Egypt;
[d] Soil and Water Department, Faculty of Agriculture, Tanta University, Egypt;
[e] Haikou Experimental Station, Chinese Academy of Tropical Agricultural Sciences, China

* Correspondence: mohamed_shokr@agr.tanta.edu.eg

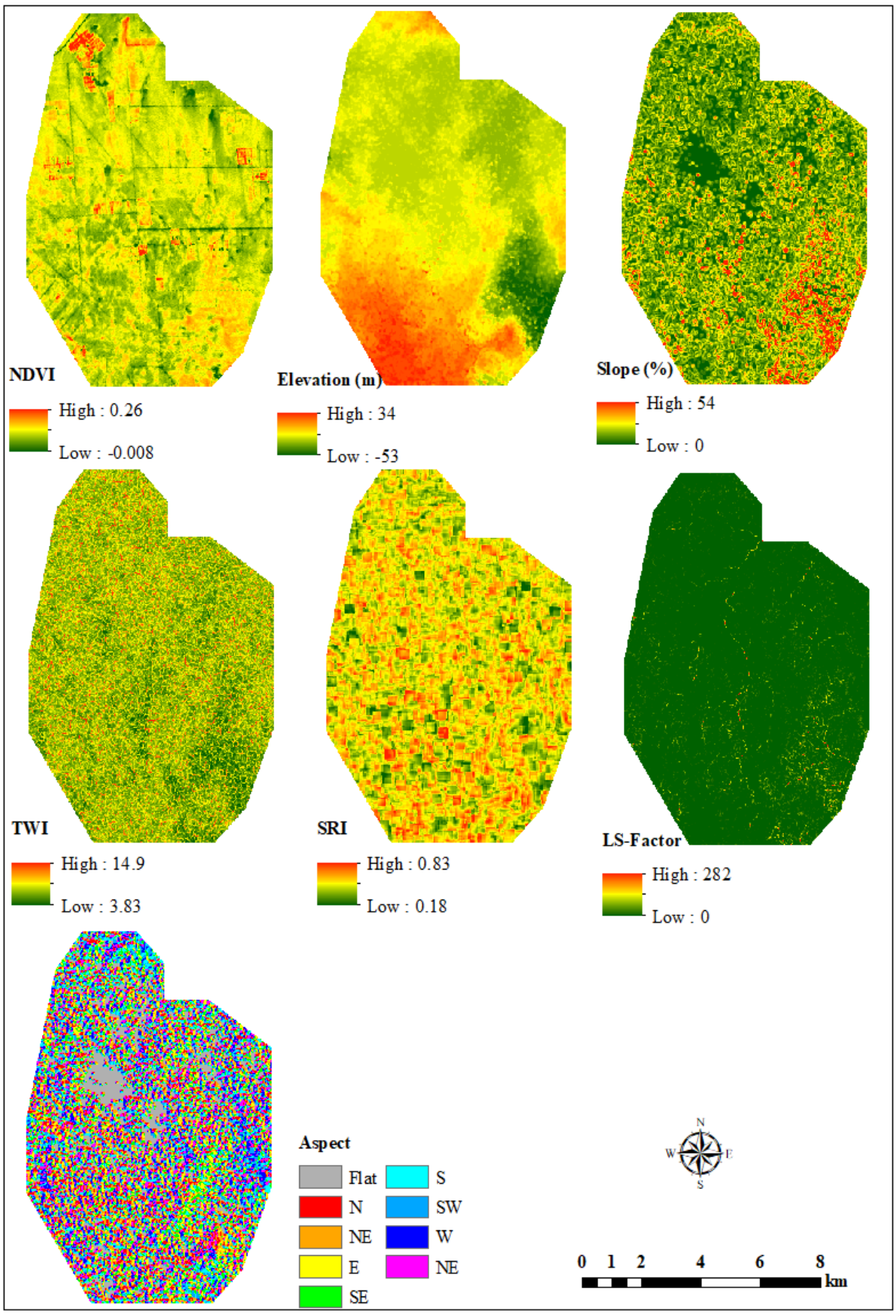


Figure S1. Vegetation and terrain attributes of the studied area

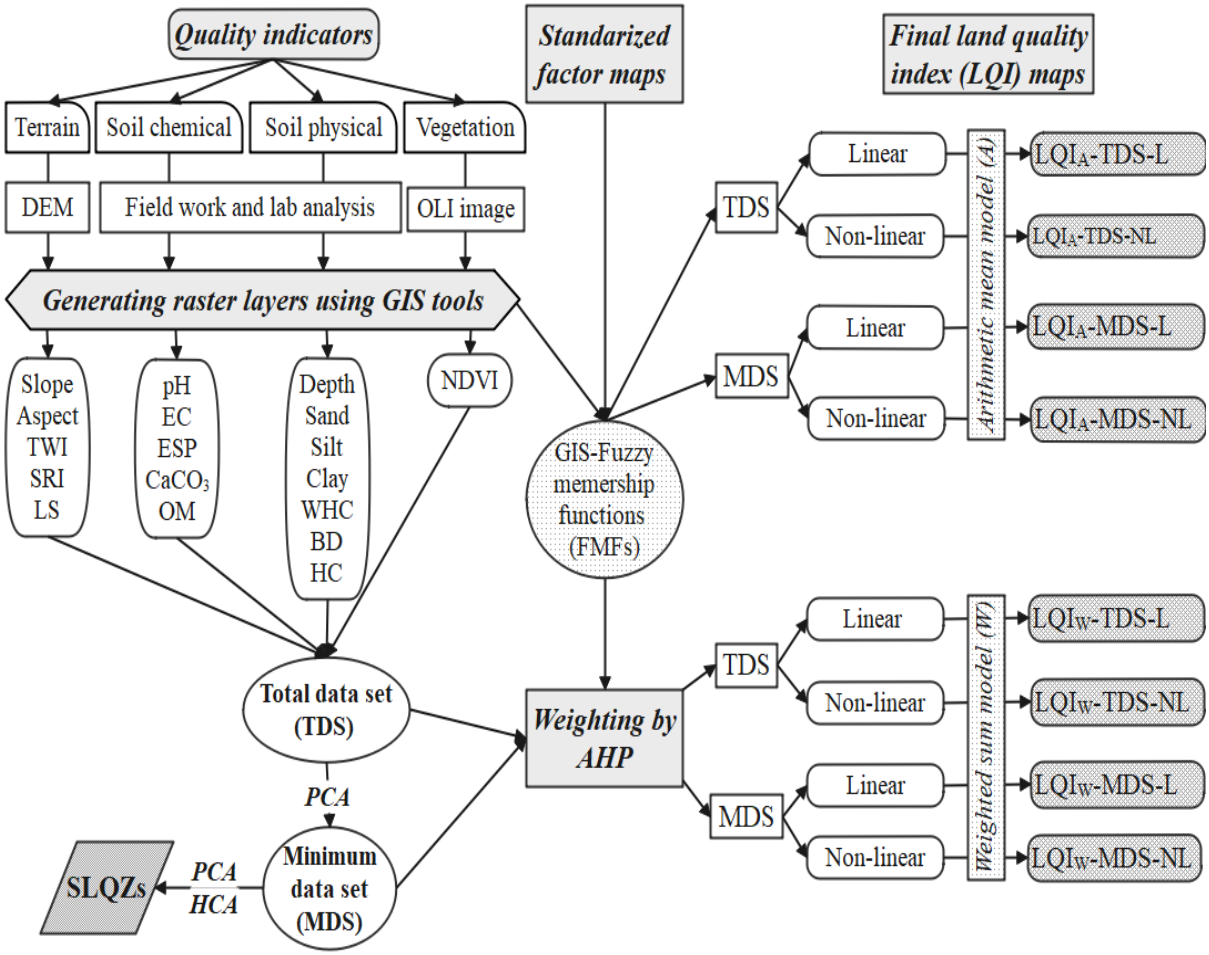
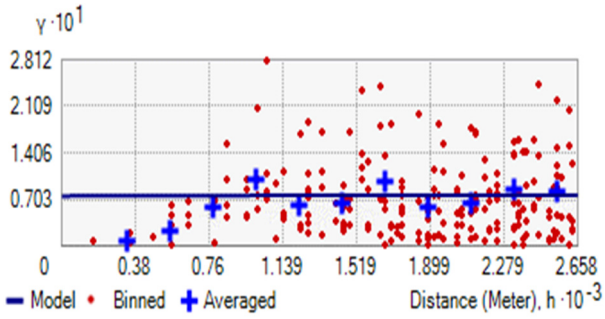
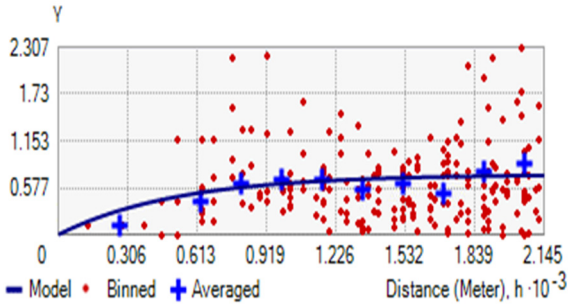


Figure S2 Schematic diagram of the methodology adopted in this work

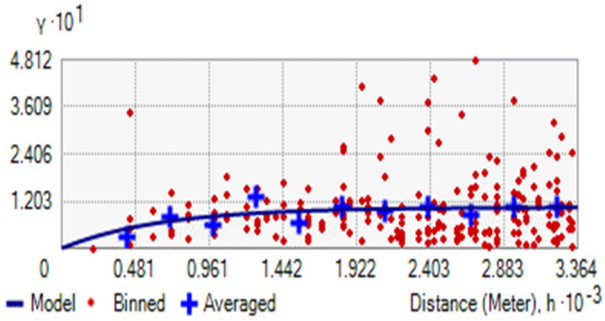
Log (pH)



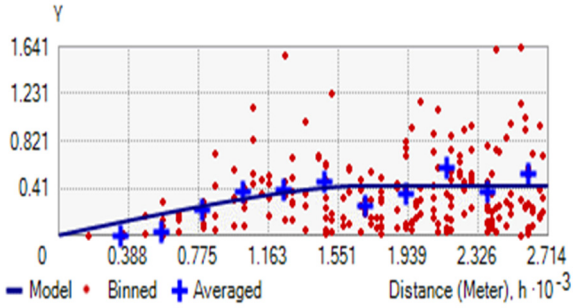
Log (EC)



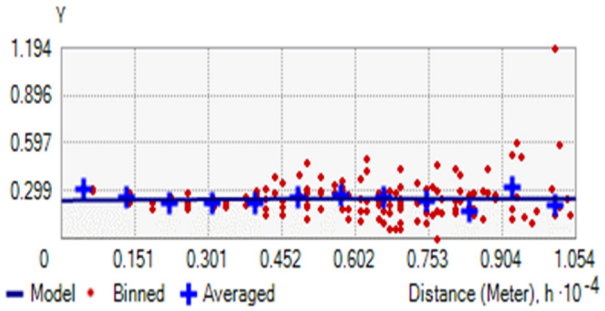
Log (ESP)



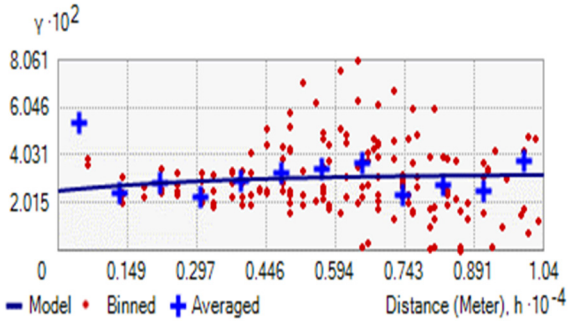
Log ($CaCO_3$)



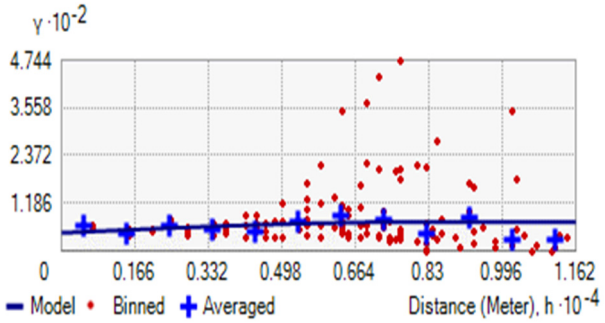
Log (OM)



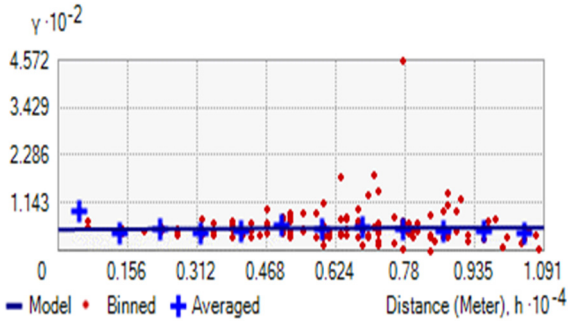
Log (Sand)



Log (Silt)

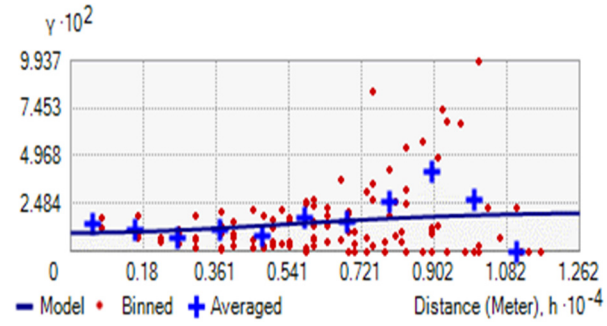


Log (Clay)

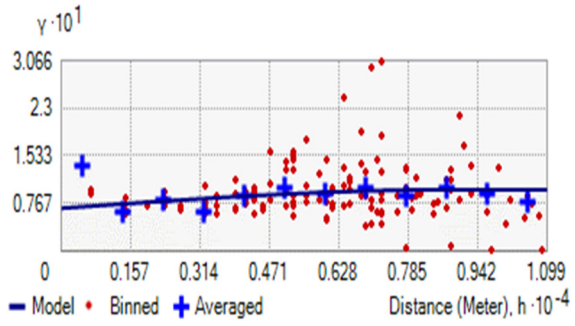


Log (Depth)

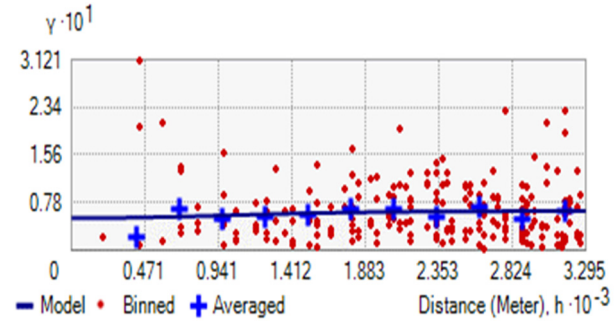
Log (WHC)



Log (BD)



Log (HC)



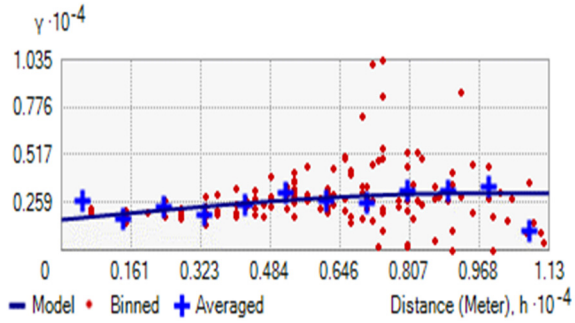


Figure S3. Semi-variogram of OK models

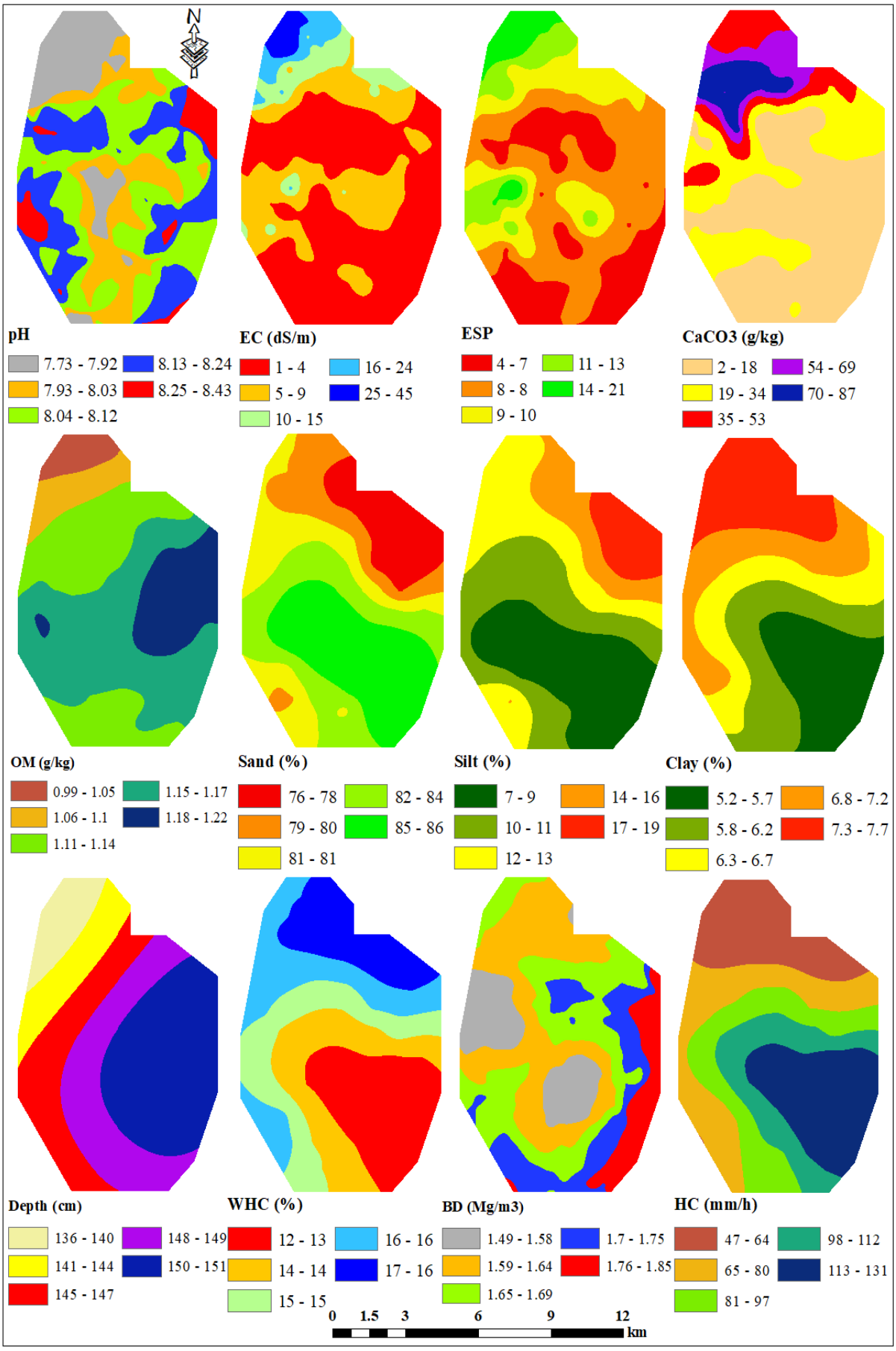


Figure S4. Spatial distribution maps of soil properties

Table S1. Descriptive statistics of main soil properties

Property	Unit	Min	Max	Mean	SD	CV, %	Normality test
pH	---	6.97	8.83	8.05	0.28	3.51	0.200 *
EC	dS m^{-1}	0.32	51.52	5.55	7.87	141.84	< 0.001
ESP	---	3.59	28.22	8.21	3.97	48.33	< 0.001
OM	g kg^{-1}	0.01	2.53	1.11	0.76	68.03	0.200 *
CaCO3	g kg^{-1}	1.31	129.42	28.30	29.70	104.92	< 0.001
Depth	cm	70.00	150.00	147.50	12.67	8.59	< 0.001
Sand	%	35.05	98.70	81.76	14.56	17.81	< 0.001
Silt	%	1.33	40.00	11.73	9.88	84.27	0.001
Clay	%	1.12	50.00	6.52	8.90	136.56	< 0.001
WHC	%	8.12	39.01	14.76	5.59	37.88	< 0.001
BD	Mg m^{-3}	1.26	2.06	1.74	0.19	11.06	0.029
HC	mm h^{-1}	1.29	219.52	85.87	56.41	65.69	0.095

EC, electrical conductivity; ESP, exchangeable sodium percentage; WHC, water holding capacity; BD, bulk density; HC, hydraulic conductivity; SD, standard deviation; CV, coefficient of variation
Normality test according to Kolmogorov-Smirnov methods. * indicates a lower bound of the true significance.

Table S2. Land quality indicators and their linear (L) and non-linear (NL) fuzzy membership functions (FMFs)

Main criteria	Sub-criterion	Associated ecosystem function	L-FMF	Lower limit	Upper limit	Reference	NL-FMF	Midpoint	Spread
Terrain quality	Slope	Soil erosion and development	Decreasing	4	30	Expert opinion	Small	4	5
	Aspect	Solar radiation and evapotranspiration	Decreasing	North	West	Abdellatif and Abuzaid [1]	Small	North	10
	TWI	Terrain control on soil wetness	Increasing	2	5	Haghighi et al. [2]	Large	5	10
	SRI	Surface resistance to wind erosion	Decreasing	0.2	0.8	Ettazarini [3]	Small	0.2	1
	LS	Surface flow volume	Decreasing	10	30	Ostovari et al. [4]	Small	10	5
Soil chemical quality	pH	Nutrient availability	Decreasing	7	9	Soil Science Division Staff [5]	Small	7	5
	EC	Plant growth and development	Decreasing	4	16		Small	4	3
	ESP	Water infiltration	Decreasing	15	50	Gupta and Abrol [6]	Small	15	5
	OM	Fertility, erosion and water relations	Increasing	0	25	Expert opinion	Large	25	1
	CaCO3	Rooting, nutrient and water relations	Decreasing	20	250	FAO [7]	Small	100	5
	Depth	Biological activity	Increasing	100	150		Large	100	10
Soil chemical quality	Sand	Fertility, erosion and water relations	Decreasing	0	60	Saleh et al. [8]	Small	60	5
	Silt		Increasing	0	50	Expert opinion	Large	50	5
	Clay		Increasing	0	30	Masto et al. [9]	Large	30	5
	WHC	Water storage, availability and movement	Increasing	15	25		Large	25	5
	HC		Decreasing	20	60	Hazelton and Murphy [10]	Small	60	5
	BD	Rooting relation and water flow	Decreasing	1.2	1.8		Small	1.2	10
Vegetation quality	NDVI	Surface protection against erosion	Increasing	0	0.5	Expert opinion	Large	0.25	2

TWI, topographic wetness index; SRI surface roughness index; LS, length of slope; NVDI, normalized difference vegetation index

Table S3. Weights of indicators included in the total data set

Main criteria	Weight (W_a)	Consistency ratio	Sub-criteria	Weight (W_n)	Consistency ratio	Final weight ($W_a \times W_n$)
Terrain quality	0.131	0.017	Slope	0.413	0.056	0.054
			Aspect	0.077		0.010
			TWI	0.106		0.014
			SRI	0.239		0.031
			LS	0.165		0.022
Soil chemical quality	0.408		pH	0.081	0.070	0.033
			EC	0.406		0.166
			ESP	0.310		0.126
			OM	0.062		0.025
			$CaCO_3$	0.141		0.058
Soil physical quality	0.375		Depth	0.330	0.087	0.124
			Sand	0.119		0.045
			Silt	0.044		0.017
			Clay	0.237		0.089
			WHC	0.144		0.054
			BD	0.070		0.026
			HC	0.056		0.021
Vegetation quality	0.086		NDVI	1		0.086

Table S4. Pairwise comparisons and weights of the minimum data set criteria

Criterion	Pairwise comparison matrix							Rank	Weight
	(1)	(2)	(3)	(4)	(5)	(6)	(7)		
(1) Slope	1	3	1	1/3	3	3	3	2	0.193
(2) SRI	1/3	1	1/2	1/3	2	2	2	4	0.108
(3) pH	1	2	1	1/4	1	2	1	3	0.120
(4) EC	3	3	4	1	4	4	4	1	0.356
(5) OM	1/3	1/2	1	1/4	1	2	1/2	6	0.076
(6) Sand	1/3	1/2	1/2	1/4	1/2	1	1/2	7	0.055
(7) NDVI	1/3	1/2	1	1/4	2	2	1	5	0.092
Consistency ratio				0.049				Sum	1.000

Table S5. Mean values of properties in the developed spatial land quality zones (SLQZs)

Zone	Number	%	pH	EC	OM	Sand	Slope	SRI	NDVI
SLQZ1	18	36	7.91bc	6.68bc	1.04abc	85.05a	2.40bc	0.53a	0.069^{de}
SLQZ2	1	2	7.66c	6.76bc	0.39c	70.64bc	1.35c	0.52a	0.09^{a}
SLQZ3	11	22	8.38a	2.89bc	0.81bc	90.37a	3.07bc	0.55a	0.069^{cde}
SLQZ4	2	4	8.09a	1.64c	1.57ab	92.87a	13.91a	0.54a	0.075^{cb}
SLQZ5	5	10	7.90bc	4.28bc	1.15abc	83.97ab	6.49b	0.36b	0.072^{bcd}
SLQZ6	4	8	8.01a	11.44b	1.79a	92.14a	5.36bc	0.57a	0.060^{e}
SLQZ7	1	2	7.94bc	45.06a	1.65ab	88.83a	4.37bc	0.48ab	0.081^{ab}
SLQZ8	8	16	8.08a	3.25bc	1.31ab	59.05c	3.57bc	0.46ab	0.064^{de}

Means with different letters indicate significant differences ($P < 0.05$)

Table S6. Spatial distributions of land quality grades according to different indices

Model	Data set	Score	Area	Land quality grade				
				Very high	High	Moderate	Low	Very low
				I	II	III	IV	V
Arithmetic mean	Total	Linear	ha	2180.54	2602.68	1734.50	870.62	557.42
			%	27.44	32.76	21.83	10.96	7.02
		Non-linear	ha	1455.27	1596.60	1664.51	2067.20	1162.18
			%	18.32	20.09	20.95	26.02	14.63
	Minimum	Linear	ha	2518.37	2576.64	1436.54	699.09	715.11
			%	31.69	32.43	18.08	8.80	9.00
		Non-linear	ha	895.60	1511.38	2334.26	2229.57	974.95
			%	11.27	19.02	29.38	28.06	12.27
Weighted sum	Total	Linear	ha	4489.62	1645.13	855.33	297.00	658.69
			%	56.50	20.70	10.76	3.74	8.29
		Non-linear	ha	1315.30	2168.90	1974.49	1588.60	898.47
			%	16.55	27.30	24.85	19.99	11.31
	Minimum	Linear	ha	4486.03	1475.60	850.26	434.77	699.11
			%	56.46	18.57	10.70	5.47	8.80
		Non-linear	ha	875.50	1789.87	2002.59	2118.49	1159.32
			%	11.02	22.53	25.20	26.66	14.59

Table S7. Pearson's correlation matrix for land quality indices (LQIs)

Index	LQI_A-TDS-L	LQI_A-MDS-L	LQI_W-TDS-L	LQI_W-MD-L	LQI_A-TDS-NL	LQI_A-MDS-NL	LQI_W-TDS-NL	LQI_W-MD-NL
LQI_A-TDS-L	1.000							
LQI_A-MDS-L	0.854**	1.000						
LQI_W-TDS-L	0.857**	0.956**	1.000					
LQI_W-MDS-L	0.826**	0.979**	0.987**	1.000				
LQI_A-TDS-NL	0.505**	0.498**	0.445**	0.468**	1.000			
LQI_A-MDS-NL	0.360*	0.540**	0.486**	0.539**	0.810**	1.000		
LQI_W-TDS-NL	0.608**	0.776**	0.783**	0.800**	0.751**	0.832**	1.000	
LQI_W-MDS-NL	0.450**	0.660**	0.636**	0.678**	0.737**	0.951**	0.938**	1.000

* Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

A, arithmetic mean; W, weighted model; TDS, total data set; MDS, minimum data set; L, linearly scored indicators; NL, non-linearly scored indicators

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