



The influence of soil pollution by heavy metals on the land suitability for irrigated wheat farming in Zanjan region, northwest Iran

Yaser Safari¹ · Mohammad-Amir Delavar²

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Abstract

The main objective of this study was to assess the land suitability for irrigated wheat farming, surrounding the Zinc Specialized Industrial Town (briefly, Zinc Town), northwestern Iran, with soils polluted by zinc (Zn), lead (Pb), and cadmium (Cd). The concentrations of heavy metals (HMs) were measured in 110 topsoil samples (0–20 cm), as well as in 65 samples of wheat grains. The limitation scores for the climatic factors, soil properties, and HMs were calculated based on their limitation for wheat cropping. Afterwards, the accumulated limitation scores were used for calculation of the land suitability membership scores using an exponential function, and then the maps were produced. The results showed that there were optimal climatic conditions for irrigated wheat, whereas due to the youthfulness of studied soils, the content of coarse fragments (CF), as the most limiting soil property, made moderate to very severe limitations in more than half of sampling points. Regarding the Iranian threshold values of 500, 75, and 5 mg kg⁻¹ as the MPC for Zn, Pb, and Cd, respectively, 7.27, 30.0, and 20.0% of soil samples were classified as the polluted soil to these pollutants. On the other hand, Pb and Cd concentrations in 24.6 (16 samples) and 29.2 (19 samples) % of cultivated wheat in the studied area exceeded the threshold value of 0.2 mg kg⁻¹, respectively, whereas Zn concentration in none of the sampled plants was higher than the threshold value of 50.0 mg kg⁻¹. Land suitability for wheat farming significantly decreased near the Zinc Town due to the HMs transferring from polluted soils to wheat grains. Therefore, potential threat of metallic pollutants for secure and safe food production should be considered as an important environmental factor to accurate assessment of land suitability for a given crop.

Keywords Calcisols · Land evaluation · Land suitability · Limitation scores · Soil contamination

Introduction

Land suitability evaluation (LSE) is vital to land use planning (Nguyen et al. 2015). In this process, matching the land characteristics with crop requirements, a suitability class ranging from highly suitable (S1) to not suitable (N2) is assigned to each parcel of land (FAO 2007). Substantial soil properties are

considered in the common LSE procedures, like the widely accepted “A framework for land evaluation” presented by FAO (FAO 1976), whereas relatively variable, management-related soil properties are less concerned (Canali et al. 2009). Therefore, it is believed that the common LSE methods are not effective to address many new agro-environmental challenges (Manna et al. 2009).

As a substantial environmental issue, the accumulation of heavy metals (HMs) in the fertile layers of soils through the rapid growth of industries may decline the soil quality (Khosravi et al. 2018). It is reported that excess HM concentrations in soil may affect the vital function of the soil to provide a safe environment for plant growth and lead to a significant decrease in final production (Hu et al. 2013). Out of that, considering HMs’ long retention time in the environment and their limited physical movement through the soil profile, the plant uptake process may provide them a big chance to transfer to the human food chain (Huang et al.

✉ Yaser Safari
yaser.safari@shahroodut.ac.ir

Mohammad-Amir Delavar
amir-delavar@znu.ac.ir

¹ Faculty of Agriculture, Shahrood University of Technology, Shahrood, Iran

² Department of Soil Sciences, Faculty of Agriculture, University of Zanjan, Zanjan, Iran

2008). Therefore, assessment of the soil pollution risk is essential to design an efficient land use planning in contaminated areas (Bagdanavičiute and Valiunas 2013).

Risk assessment of soil pollution by HMs is commonly done by mapping the interpolated values of HM concentrations throughout a given area. In these maps, regulations to protect humans from toxicities related to HMs are primarily based on soil quality reference or threshold values (Manga et al. 2014). In this case, comparing the specific HM concentration in each map unit with its predetermined threshold value, these units will be classified into the suitable or non-suitable area for crop farming, based on their HM contents lower or higher than the threshold values, respectively (Romic et al. 2007). It is obvious that in this procedure, some land units with different HM contents are recognized as equally polluted areas, whereas the different pollution intensity within these areas may affect the HM uptake by crops. For example, considering the threshold value of 5 mg kg^{-1} (Department of Environment of Iran 2013) for separating the polluted and non-polluted soil to cadmium (Cd), both of the soils with 6 and 60 mg kg^{-1} Cd concentration will be classified as polluted soils, without considering the fact that Cd concentration in second soil is 10 times higher than the first. Furthermore, this classification system does not pay attention to the significant differences of plant abilities to take up the HMs by their roots (Kaplan et al. 2005). Therefore, an investigation of the transfer characteristics of the HMs from soils to the plants for each particular soil-plant system is recommended (Li et al. 2010).

The Zinc Specialized Industrial Town (briefly, Zinc Town), located in the south of Zanzan city, northwest Iran, is one of the most productive metallurgical plants in the Middle East. This industrial complex was established in 1996 with a current

consumption of about one million tons of raw ores and a production of 0.19 million tons of zinc (Zn) per year. The fertile agricultural lands located around the Zinc Town are extensively used for growing cereal crops, especially wheat (*Triticum aestivum* L.). Considering wheat ability to take up different HMs by its roots (Boussen et al. 2013), it is likely that HMs in the contaminated soils may enter the human food chain through the root uptake processes. Therefore, the present study tries to consider the risk of soil pollution by heavy metals as a soil factor affecting the land suitability for specific crop for the first time. The main objective of this study was to develop a new method for assessing the land suitability for irrigated wheat farming, regarding the probability exceeding Zn, Cd, and lead (Pb) contents in grown wheat plant than the normal range.

Materials and methods

Study area

The study area is located in the southern part of Zanzan city, northwestern Iran, between the latitudes $36^{\circ} 33'$ and $36^{\circ} 40' \text{ N}$ and the longitudes $48^{\circ} 23'$ and $48^{\circ} 37' \text{ E}$, covering an area of about 10,000 ha (Fig. 1). Generally, it is a gently undulating plain with slopes ranging between 1 and 4% and altitude about 1670 m above sea level. Mean annual precipitation and temperature during the last 50 years are 302.8 mm and 11.1° C , respectively. According to Soil Taxonomy (Soil Survey Staff 2014a), the studied soils are mainly classified as Entisols and the soil moisture and temperature regimes of the region are

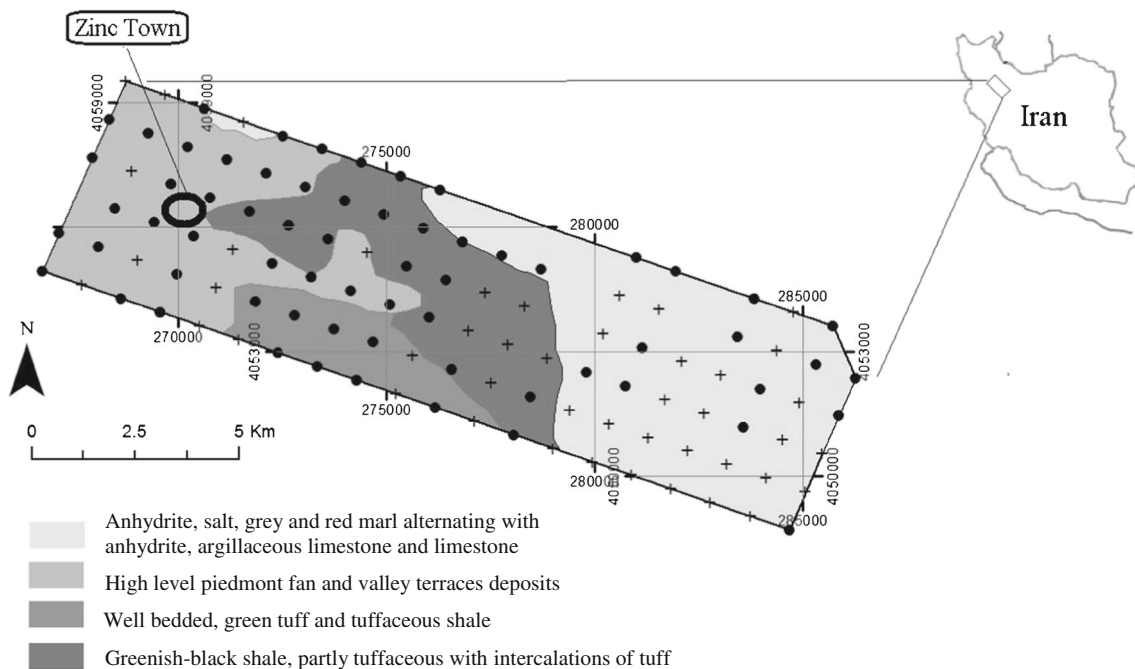


Fig. 1 Geologic map of study area along with soil (black circle) or soil and wheat (cross) sampling points in the Zanzan province, northwest Iran

Table 1 Landscape, soil, and climatic requirements for irrigated wheat farming (Sys et al. 1993)

Land characteristics		Class, degree of limitation, and rating scale				
	SI	S2	S3	NI	N2	
	0	1	2	3	4	
	100–95	95–85	85–60	60–40	40–25	
	0–1	1–2	2–4	4–6	> 6	
Landscape and soil	Slope (%)	Moderate	Imperfect	Poor and aeric	Poor not drainable	
	Drainage	C < 60s, SiC, Co, Si, SIL, CL	C > 60v, SC, C > 60s, L	SL, LIS	Cm, SiCm, LcS, fS, cS	
	Texture/structure	3–15	15–35	35–55	> 55	
	Coarse fragment (volume %)	90–50	50–20	20–10	> 20	
	Soil depth (cm)	20–30	30–40	40–60	> 60	
	CaCO ₃ (%)	3–0	5–10	10–20	> 20	
	Gypsum (%)	24–16	< 16 (-)	< 16 (+)	-	
	Apparent cation exchange capacity (Cmol/kg clay)	80–50	50–35	< 35	-	
	Base saturation (%)	6.5–6	6–5.6	5.6–5.2	> 8.5	
	pH (H ₂ O)	7.5–8.2	8.2–8.3	8.3–8.5	> 10	
	Electrical conductivity (dS/m)	1–3	3–5	5–6	> 10	
	Exchangeable sodium percentage (%)	15–20	20–35	35–45	> 45	
Climatic	Mean temperature of the growing cycle (°C)	20–23	23–25	25–30	> 30	
	Mean temperature of vegetative stage (°C)	15–12	12–10	10–8	< 8	
	Mean temperature of flowering stage (°C)	8–6	6–4	4–2	< 2	
	Mean temperature of ripening stage (°C)	12–18	18–24	24–28	> 28	
	Mean daily minimum temperature of the coldest month (°C)	14–12	12–10	10–8	< 8	
	Mean daily maximum temperature of the coldest month (°C)	18–22	26–32	32–36	> 36	
	Mean daily minimum temperature of the coldest month (°C)	20–16	14–12	12–10	< 10	
	Mean daily maximum temperature of the coldest month (°C)	20–24	30–36	36–42	> 42	
	Mean daily minimum temperature of the coldest month (°C) if	< 8	> 8	8–19	-	
	Mean daily maximum temperature of the coldest month (°C) if	< 21	If	If	-	
			< 21	> 21		

C clay, Si silt, L loam, S sand, f fine, m massive, c coarse, v very fine, o oxisol structure

Table 2 Limitation scoring system introduced by Zhang (1989)

Limitation degree	0 (no limitation)	1 (slight limitation)	2 (moderate limitation)	3 (severe limitation)	4 (very severe limitation)
Limitation score	0	1	3	9	27

xeric and mesic, respectively. Irrigated and rain-fed wheat are the most common land uses in Zanjan region.

Sample collection and analyses

Designing a regular grid sampling method, which is the most common geostatistical sampling approach (Webster and Oliver 2001), in agricultural soils around the Zinc Town, a total of 110 sampling locations with 1000-m intervals were achieved. It is recommended that top 1 m depth of the soil should be considered to determine its capability for supporting the annual crops (Sys et al. 1993). Accordingly, soil samples at all sampling sites were collected from the depths of 0–25, 25–50, 50–75, and 75–100 cm, with the aid of a global positioning system (Fig. 1). The soil samples were taken to the laboratory, where they were air-dried and then passed through a 2-mm sieve. Prepared samples were subsequently analyzed for required soil properties in LSE (Sys et al. 1993) using standard methods (Soil Survey Staff 2014b). Besides, required climatic data for LSE were obtained from Znanjan Synoptic Meteorological Station (Zanjan Meteorological Administration 2015) for a 50-year period (1965–2015).

Meanwhile, for the purpose of assessing the land suitability for irrigated wheat regarding the risk of soil pollution by HMs, soil samples at all sampling locations were taken from the surface layer (0–20 cm), which the roots of wheat mainly distribute in. These soil samples were digested using HCl-HNO₃ for the determination of the near-total concentrations of Zn, Pb, and Cd (Sposito et al. 1982). The analyzed HMs were reported as the main soil pollutants in the studied area (Khosravi et al. 2018). Available contents of the studied HMs in the soils were extracted using the diethylenetriaminepentaacetic acid (DTPA) method (Lindsay and Norvell 1978).

To assess the more realistic limitation of the studied contaminated soils for wheat farming, probability of HMs entering the edible part of cultivated crop (wheat grains) was evaluated. For this purpose, at the soil sampling sites which were

under wheat cultivation at the time of sampling (65 points) (Fig. 1), wheat samples were collected shortly before crop harvesting. Wheat grains were ground with an agate mill, homogenized and sieved through a 0.4-mm polyethylene sieve. These prepared samples were digested in a solution of 70% aqua regia (HNO₃ + concentrated HCl) and 30% H₂O₂ and analyzed for Zn, Pb, and Cd by atomic absorption spectrometry (Westerman 1990). Finally, the data were statistically analyzed using SPSS (ver., 21.0, SPSS Inc., USA) software.

Land suitability assessment

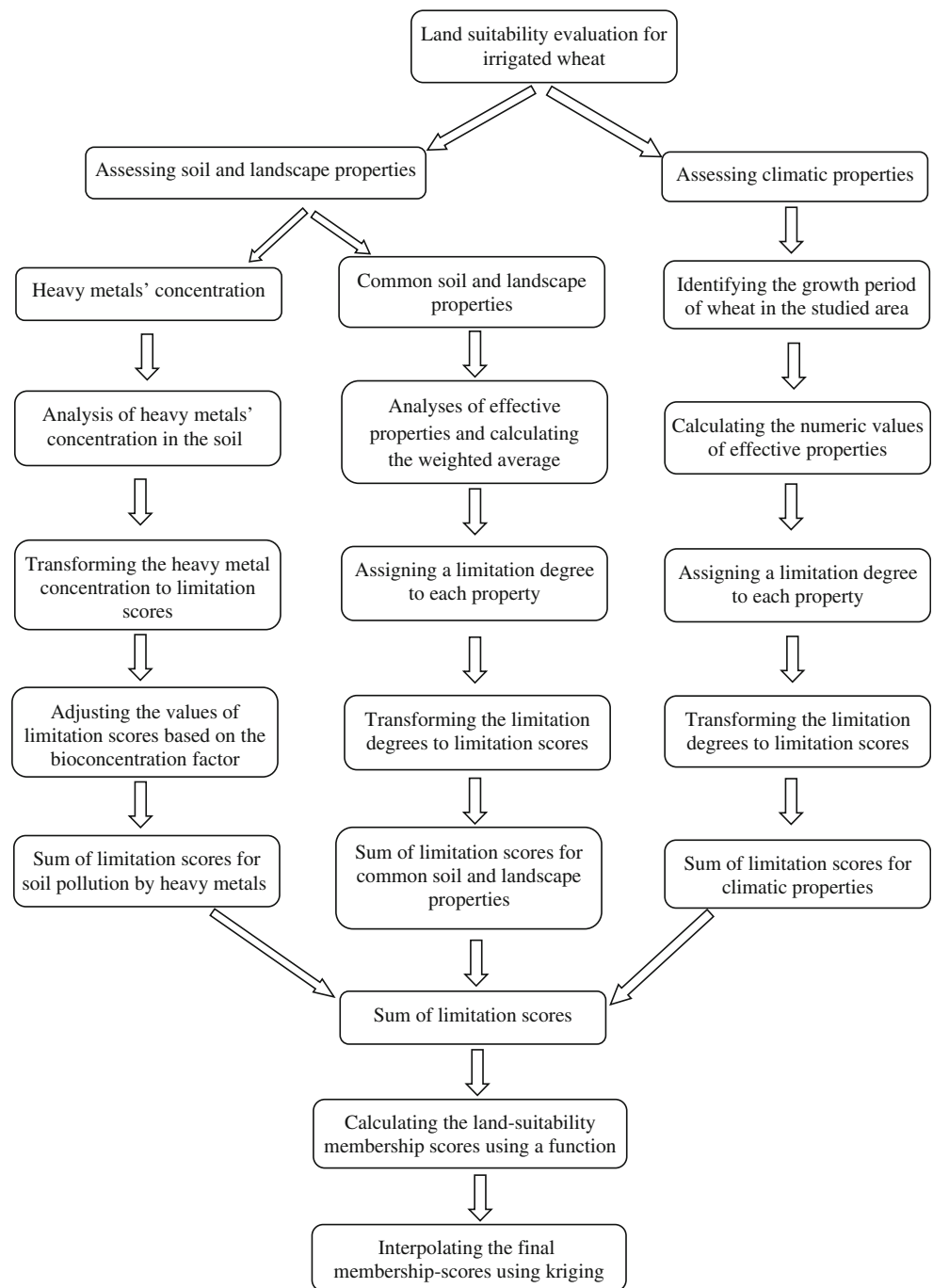
The FAO Framework for Land Evaluation states that land use requirements should match the observed land characteristics (FAO 1983). To examine the compatibility of measured soil properties with optimum requirements for wheat plant, the weighted average of each soil property in each sampling point was recalculated. For this purpose, the studied depth of soil (100 cm) was divided to four equally thick layers (25 cm) and the measured content of each soil property in these layers was multiplied by the weighted coefficients of 1.75, 1.25, 0.75, and 0.25, for each section from up to down the soil profile, respectively (Sys et al. 1991a, b). Afterwards, the weighted values were matched with wheat plant requirement table presented by Sys et al. (1993). Consequently, the limitation degree of soil properties in soil sampling points was recognized. The limitation degree of required climatic properties for irrigated wheat was achieved in the similar way. Climatic, soil, and landscape requirements for irrigated wheat are summarized in Table 1 (Sys et al. 1993).

Many of the soil properties, which are considered in LSE procedure, are expressed using different scales and also have different units (Reshmidevi et al. 2009). Therefore, representation of these attributes in a common scale (standardization) and their combination in LSE needs a systematic procedure (Elsheikh et al. 2013). The scoring system is extensively used in land evaluation studies to standardize the soil variables to the same scale (Triantafilis et al. 2001; Reshmidevi et al. 2009; Bagdanaviciute and Valiunas 2013). In the present study, the scoring system introduced by Zhang (1989) was used to transfer the calculated degrees of limitation to limitation scores (LSs). In this system, for each of five the defined degrees of limitation by FAO (FAO 1976), a limitation score is introduced (Table 2). Finally, calculated LSs for all soil and climatic properties were summarized as final climate and soil limitation score to express the overall limitation from all land characteristics for the studied land use.

Table 3 Threshold values for selected HMs in Iranian soils (mg kg⁻¹) along with transformation coefficients calculated for given threshold concentrations

	Maximum permissible	Critical	b_0	b_1
Zn	500	7500	0.00047	1.23048
Pb	75	820	0.00244	1.39319
Cd	5	20	0.02088	2.40368

Fig. 2 The procedure for assessing the land suitability for irrigated wheat



For the soil limitations arisen from soil pollution by HMs, the concentration values were converted to limitation scores using the exponential transfer function introduced by Romić et al. (2007) (Eq. 1). Selection of such an exponential function for calculating the LSs is due to the fact that the trends of HM uptake by wheat plant, as an excluder plant (Boussen et al. 2013), are exponential too (Baker 1981). This function is determined by two threshold values: permissible concentration and seriously polluted soil:

$$LS = \begin{cases} b_0 \times HMC^{b_1-1} & \text{if } HMC \geq x_1 \text{ and } 0 \text{ if } HMC < x_1 \end{cases} \quad (1)$$

where LS is the limitation scores, b_0 and b_1 are the coefficients, HMC is HM concentration, and X_1 is the maximum permissible concentration (MPC).

It should be noted that most of the soils in Iran are calcareous with high contents of calcium carbonate equivalent (CCE). The high carbonate contents have caused slightly to fairly severe alkaline conditions in these soils (pH between 7.4–8.8) (Karami et al. 2009). Regarding relatively strong effects of soil pH and CCE on HM behavior in the soil (Kaplan et al. 2005), maximum permissible and serious soil pollution thresholds for

Table 4 Summary statistics of the selected soil properties (weighted average values for the first 100 cm of soil depth)

Variable	Mean	Minimum	Maximum	Median	Stdev	Skewness	Kurtosis	CV (%)	K-S p^b
pH	7.78	7.45	8.15	7.79	0.12	-0.20	0.61	1.54	0.46
CF (%)	18.5	4.8	64.4	15.3	10.81	1.21	2.15	58.5	0.00*
CCE (%)	19.3	5.7	45.3	16.9	9.17	0.73	-0.24	47.48	0.04*
EC (dS m ⁻¹)	0.55	0.27	1.32	0.53	0.16	2.06	6.57	29.31	0.00*
SAR ((meq l ⁻¹) ^{0.5})	0.39	0.17	0.93	0.37	0.11	1.38	4.40	29.35	0.00*
Clay (%)	31.8	10.1	42.7	31.7	6.85	-0.28	0.94	21.53	0.28
Sand (%)	42.0	17.7	72.5	41.2	10.04	0.53	0.39	23.94	0.00*

K-S p : the significance level of Kolmogorov-Smirnov normality test

pH soil reaction, CF coarse fragment, CCE calcium carbonate equivalent, EC electrical conductivity, SAR sodium adsorption ratio

*Significant at $p < 0.05$

different pollutants were recommended by Department of Environment of Iran (2013) (Table 3).

The b_0 and b_1 coefficients can be estimated by solving the linear regression model (Eq. 2):

$$\ln(\text{LS} + 1) = \ln b_0 + b_1 \times \ln(\text{HMC}) \quad (2)$$

In this case, three LSs were attributed to the given HMCs: $\text{LS} + 1 = 0$ for $\text{HMC} = 0$, $\text{LS} + 1 = 1$ for $\text{HMC} = \text{maximum permissible concentration}$, and $\text{LS} + 1 = 27$ for $\text{HMC} = \text{soil serious pollution (critical) threshold}$. After calculating the LS for each soil sampling point, to assess the more realistic probability of final wheat product pollution by HMs, these values were multiplied by the mean bioconcentration factor (BCF) for each HM. BCF was calculated as the ratio of the given HM concentration in wheat grains to its bioavailable concentration in soils ($\text{BCF} = C_{\text{plant}}/C_{\text{soil}}$) (Wang et al. 2013). This coefficient is widely used to evaluate the potential HM accumulation by plants (Chopin and Alloway 2007). Finally, adjusted LSs for HMC were summarized with estimated LSs for soil and climatic properties and accumulated limitation scores were used to estimate the land suitability membership score using an exponential function (Triantafilis et al. 2001) (Eq. 3):

$$\mu_i = e^{(-0.1 \times \text{accumulated limitation score})} \quad (3)$$

where μ_i is the suitability membership of the land utilization type of interest, with values ranging between 0,

membership to the non-suitable land utilization class, and 1, membership to the suitable land utilization class. Finally, the values of land suitability membership scores were interpolated through the studied area using ordinary kriging (OK) estimator in ArcGIS software (ver. 10.3; ESRI). Figure 2 presents a general view of the procedure used in this research for land suitability assessment for irrigated wheat.

Results and discussion

General soil properties

Table 4 shows summary statistics of the studied soil attributes. The soils have relatively high contents of CCE (mean 19.3%), causing the soil to be classified as a calcareous soil (Qishlaqi et al. 2009). These calcareous conditions not only lead to slight to moderate soil alkalinity (soil pH ranged from 7.45 to 8.15), but also seem to affect the low contents of electric conductivity (EC) and sodium adsorption ratio (SAR) of the studied soils (Table 4). Although relatively high contents of sand were measured in the studied soils, these soils are generally classified as heavy-textured soils due to high clay contents (Table 4).

Table 5 Average values of essential climatic properties for LSE for irrigated wheat, their limitation degrees, and assigned LSs

Climatic property	Values	Limitation degree	Limitation score
Mean temperature of the growing cycle (°C)	13.4	1	1
Mean temperature of vegetative stage (°C)	8.7	0	0
Mean temperature of flowering stage (°C)	15.2	0	0
Mean temperature of ripening stage (°C)	21.3	0	0
Mean daily minimum temperature of the coldest month (°C)	-0.7	0	0
Mean daily maximum temperature of the coldest month (°C)	12.7		

Table 6 Percentage of soil sampling points in each defined limitation degrees by FAO based on the given soil properties

Soil properties	0	1	2	3	4
CF	0.0	49.4	43.6	4.7	2.3
CCE	65.9	28.2	5.9	0.0	0.0
pH	87.1	12.9	0.0	0.0	0.0
EC	100.0	0.0	0.0	0.0	0.0
SAR	100.0	0.0	0.0	0.0	0.0
Soil texture	12.9	83.5	3.6	0.0	0.0

CF coarse fragments, CCE calcium carbonate equivalent, pH soil reaction, EC electrical conductivity, SAR sodium adsorption ratio

Soil and climate limitations for irrigated wheat

The mean contents of essential climatic properties for determining the land suitability for studied land utilization type, their limitation degrees (according to Sys et al. 1993), and their assigned LSs (according to Zhang 1989) are shown in Table 5. Since the irrigated wheat farming is performed in the present study (not rain-fed), rainfall was not considered.

There were optimal climatic conditions for irrigated wheat; thus, the region received just 1 limitation score arisen from the mean temperature of the growing cycle (Table 5). Matching the measured soil properties in each sampling point with the optimum soil conditions for wheat cultivation (Sys et al. 1993), the percentages of soil sampling points which are classified in each defined limitation degree (FAO 1976) are presented in Table 6.

Since some of the soil and landscape properties (depth, gypsum content, slope, micro-relief, etc.) and wetness conditions (drainage, flooding, etc.) had no limitation for the studied land use type (data not showed), they were not considered in LSE process. Furthermore, base saturation percentage and cation exchange capacity (CEC) contents are not considered as land suitability indices in arid and semiarid regions (Sys et al. 1991a), because of the youthfulness of soils in these areas. Among the studied soil properties, the content of coarse

fragments (CF) made some serious limitations for wheat farming in the studied area so that more than half of sampling points showed moderate to very severe limitations in respect of this property (Table 6). This high observed limitation of CF may be attributed to the youthfulness of studied soils, because according to Soil Taxonomy (Soil Survey Staff 2014a), the studied soils are mainly classified as Entisols, which are poorly developed and immature soils maintaining their rock structure to some extent. Figure 3 shows the spatial distribution of coarse fragments in the studied area.

HM limitations for wheat farming

Figure 4 shows the percentages of soil sampling points which exceeded the MPC and critical threshold values of studied HMs, as well as percentages of wheat sampling points that exceeded the MPC of studied HMs in wheat grain. Based on Zn, Pb, and Cd concentrations in soil, 7.27, 30.0, and 20.0% of soil samples were higher than the MPC for these elements, respectively. This may indicate that among the studied HMs, Pb is the most serious pollutant in this area. On the other hand, in respect of exceeding the MPC of Zn in the wheat grains, none of the sampled plants were higher than the threshold value of 50.0 mg kg⁻¹ (Fig. 4) (Huang et al. 2008), whereas based on exceeding the MPC of Pb and Cd in wheat grains, 24.62 (16 samples) and 29.23 (19 samples) % of cultivated wheat in the studied area were higher than the threshold value of 0.2 mg kg⁻¹, respectively (Fig. 4) (FAO/WHO 2012). Accordingly, it seems that due to the easier uptake by wheat roots and higher transfer to the grains compared with Pb (Huang et al. 2008), Cd is the most dangerous pollutant for wheat farming in the studied area against its low concentration in the soil. This observation clearly showed that due to the short-range variations of soil properties (Usovicz and Lipiec 2017), assessment of pollutants risk based on a constant threshold value may lead to some unrealistic results.

To highlight the role of soil limitations arisen from soil pollution by HMs, the final suitability maps for irrigated wheat

Fig. 3 Spatial distribution map of coarse fragments in the studied soils

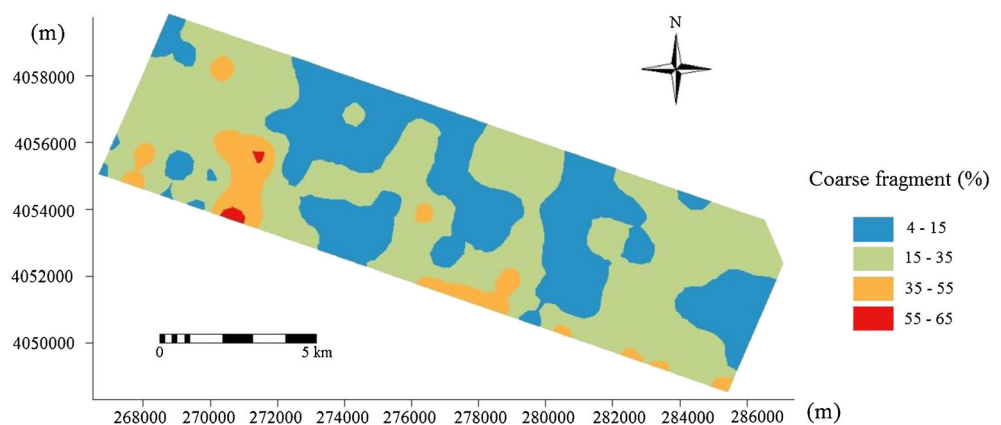
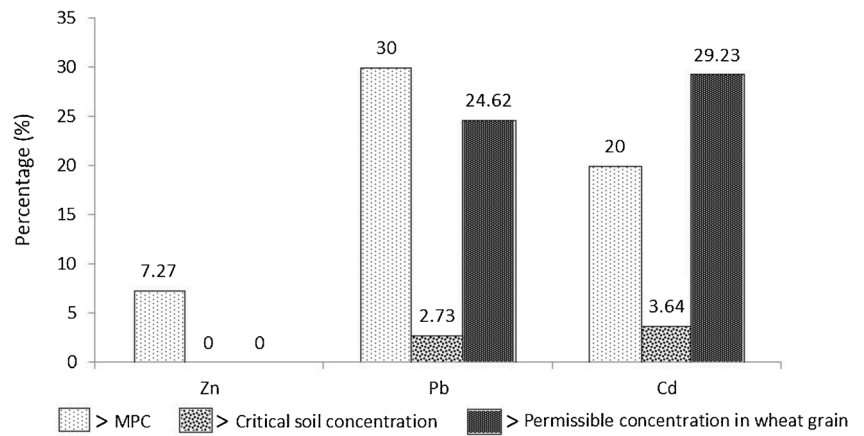


Fig. 4 Percentages of soil and wheat sampling points exceeding the MPC and critical threshold values of studied HMs

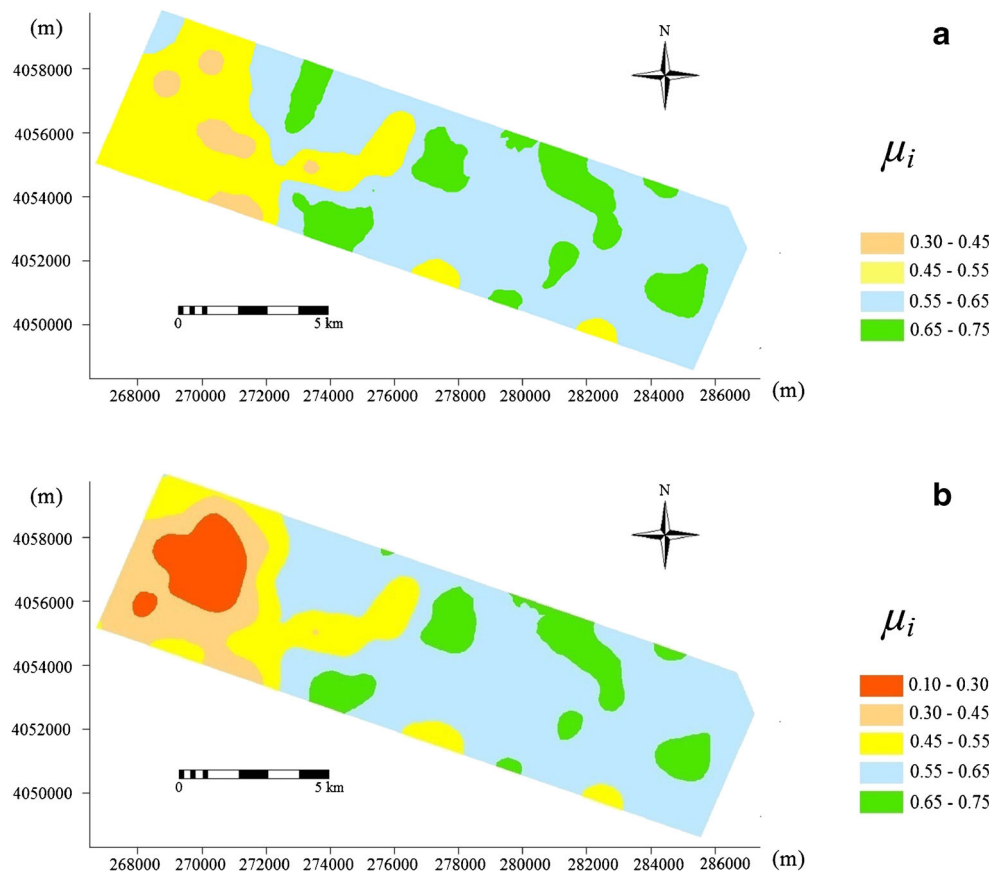


without and with consideration of the assigned LSs to HMs are presented in Fig. 5a, b, respectively. As shown in Fig. 5a, the least suitable lands for wheat farming are located in the northwest of studied area, whereas the highest values of suitability membership are observed in the central and southeast parts of this area. Totally, the interpolated values of suitability membership showed appreciable variability through the area (Fig. 5). This may suggest that the studied soil properties have relatively high short-range variations, which is originated from the soil substantial characteristics or management practices (Burrough 2006). It

has been reported that abbreviating the short-range variation of soil properties in traditional LSE procedures may result in unsatisfactory results in estimation of land suitability for different crops (Ziadat 2007; Safari et al. 2013; Nguyen et al. 2015).

It is believed that crisp classification of land parcels to suitable and not suitable for specific land uses in conventional boolean-based LSE procedures ignores the continuous nature of soil and landscape variation (Ahamed et al. 2000) and may finally lead to misclassification of sites that just fail to match strictly defined requirements (Keshavarzi et al. 2010).

Fig. 5 Final suitability map for irrigated wheat, based on **a** climatic and soil limitations and **b** climatic, soil, and HM limitations (prepared by ordinary kriging method)



Therefore, it seems that separate small delineations that are differentiated based on their values of suitability membership in Fig. 5a are the realistic reflectance of the observed soil variation in the studied area. In line with this finding, Mokarram et al. (2011) declared that continuous fuzzy-based land suitability classification allows obtaining results that seem to be corresponded with the current conditions in the area. However, controlling this highly variable suitability of studied lands for irrigated wheat farming needs precise and thoughtful management strategies.

Comparing Fig. 5a, b revealed that the general trend of land suitability for irrigated wheat through the area is similar in both maps, so that even with respect to the HM limitations for wheat farming, the interpolated values for suitability membership in central and southeast parts of the studied area are less affected. On the other hand, the values of suitability membership in the northwest part of the area, i.e., the lands located around the Zinc Town, have significantly decreased in Fig. 5b compared with Fig. 5a. According to Reshmidevi et al. (2009), the lands with suitability membership less than 0.30 were considered as the non-suitable for wheat farming. Therefore, it is observed that without consideration of the pollution risk of final wheat product, all of the studied lands can be considered as suitable lands for wheat farming (Fig. 5a), whereas considering this serious risk, about 10% of the studied lands have no suitability for wheat farming. This observation clearly proved that industrial activities related to Zn production caused to simultaneous entrance of several HMs to the adjacent soils and lead to degradation of the lands in the studied area. Accordingly, it is suggested to pay more attention on the potential threat of accumulated HMs in surface soil layers to the real land suitability for secure food production and to the health of inhabitants through consumption of grown wheat in the studied area.

Conclusion

In the present study, the FAO approach for LSE (FAO 1976) which is modified by Zhang (1989) with respect to limitation scores was used to achieve the continuous land suitability map for irrigated wheat. Since the studied area was polluted with Zn, Pb, and Cd, in addition to the common soil properties in LSE, transferring the HMs from the underlain soil to wheat grains was considered as another land limitation for the investigated land use. The results showed that there were optimal climatic conditions for irrigated wheat, whereas some soil properties especially the content of CF made some serious limitations for wheat farming in the studied area. Therefore, mapping the land suitability membership scores with respect to the common soil and climatic properties revealed that nearly all of the studied lands are suitable for irrigated wheat farming. Adding the LSs related to HMs to the calculated LSs for

common properties caused a significant decrease in values of land suitability membership scores, especially in the lands nearby the Zinc Town. Therefore, it can be concluded that the land which is located around the Zinc Town are not appropriate for wheat farming and a change of land use is strongly recommended to limit the soil pollution risk. Unlike the observed soil alkalinity and relatively high pH values, serious amounts of Cd and Pb were transferred to grown wheat grains, so that Cd and Pb in 19 and 16 wheat samples exceeded the MPC of 0.2 mg kg⁻¹, respectively. These findings clearly highlighted the role of industrial activities to facilitate the entrance of dangerous elements into the human food chain.

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