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ORIGINAL ARTICLE

Spatial repartition and contamination assessment of heavy metal in agricultural soils of Beni-Moussa, Tadla plain (Morocco)

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Abstract

The focus of this study is to determine the degree of soil pollution in Beni-Moussa irrigated perimeter. The soil is sampled at 25 various stations all through the perimeter to analyze a set of physical–chemical parameters like pH, organic matter (OM), carbonate content (CaCo3), granulometry, magnetic susceptibility at low frequency (χLF) and heavy metals (Zn, Cr, Pb, Cu, As, Ni, Cd, and Fe). Pollution indices (Geo-accumulation index (Igeo), enrichment factor (EF), contamination factor (CF), pollution Load Index (PLI), and potential ecological risk assessment (PER) are used to evaluate the degree of pollution. The achieved results imply that the soil is alkaline, rich in OM and CaCo3, and has a silt texture. The soil EF and CF were: Cu > As > Ni > Zn > Cr > Cd > Pb. The PLI values indicate anthropogenic contamination originates from human and agricultural activities located around Ouled Ayad, Had Bou Moussa, and Afourer. Moreover, χLF is significantly positively correlated with PLI. The results further attest that PLI can be estimated from χLF through the following equation $\mathrm{PLI} = 0.8\chi\mathrm{LF} + 1$ The study area presents low PER. Statistical analysis methods (Pearson correlation, principal component analysis, and cluster analysis) were used and the obtained results show that As, Cd, Cu, Zn, Cr, and Ni have similar sources.

Our study provides updated information on the state of Beni Moussa soil from the point of view of metallic contamination, provides spatial distribution maps, and identifies the main sources of pollutants to rationalize the exploitation of this natural resource within the framework of sustainable development.

Keywords Heavy metals · Anthropogenic pollution · Irrigated perimeter · Tadla plain · Agricultural soils

Introduction

Following the increase in the food need of population, soil quality assessment has become a challenge, allowing decision-making in the usage of fertilizers, irrigation management, and nutrition to carry out the best irrigation techniques, fertilization, and soil preservation as a naturally nutritious resource, thus increasing production. 80% of the world poor countries rely on agriculture since it is the key source of income for this social class. This sector contributes to poverty alleviation, income increase, food hygiene and freeing biologically available heavy metals into the surrounding (Martin et al. 2006). In the Tadla plain, the water scarcity and high fertilizer costs lead farmers to use wastewater for irrigation (Chaney 1988), which significantly contributes to the increase of toxic elements in soil (Mapanda et al. 2005). Naturally, heavy metals are present in the rock. They may be inherited from source rocks (lithogenic origin), trained during pedogenesis processes (pedogenic origin) or can be originated from anthropogenic activities (El Baghdadi et al. 2011, 2012, 2015). According to Mortvedt (1996), chemical fertilizers are the main sources of metallic soil contamination. Kabata-Pendias (2011) suggests that other agrochemical products might be a source of soil contamination. A large number of studies have proved that the continual usage of organic, chemical and agrochemical fertilizers such as insecticides, herbicides, fungicides, sewage slurries, and wastewater favor the biological buildup of heavy metals in soils subject to intensive agriculture (Reuss and Dooley 1976; Ayuso et al. 1996; Mortvedt 1996; Ihnat and Fernandes 1996; Harmon et al. 1998; Worthington 2001; Goi et al. 2006; Haroun et al. 2009). Under specific biogeochemical

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conditions, these elements can pass through the soil solution (Mench et al. 2000) and can be absorbed by plants (Jalil et al. 1994a; b) or seeped into the groundwater and precipitate as toxic elements (Christensen et al. 1996). The consumption of this water by animals and plants allows these toxic elements to pass immediately into the food chain (Tomgouani et al. 2007). It is, therefore, crucial to take stock of soil quality in such a way as to quantizes the riskiness.

Several studies confirm the availability of the relation between the magnetic susceptibility and the metallic pollutants in soil which is polluted by man's activities (Petrovsky et al. 2001; Sobanska 1999; Spiteri et al. 2005; Lu and Bai 2006; Lu et al. 2007; Yang et al. 2007, 2012; Jordanova et al. 2008; Morton et al. 2009; Canbay et al. 2010; Karimi et al. 2011; El-Baghdadi et al. 2011; El Baghdadi et al. 2012; Wang et al. 2013), which justifies the importance of the correlation between heavy metals and the magnetic susceptibility. Given that the accumulation of heavy metals in agricultural lands depends on physical–chemical properties such as texture, organic matter, PH, and carbonate content.

Modern geostatistics si a branch that develops applied statistics with a large variety of models and methods for analysis, treatment, and representation of spatial distribution data (Meshalkina 2007). This allows predictions to be made at non-sampled points and the degree of uncertainty associated with these predictions to be assessed (Oumenskou et al. 2018). The universal kriging technique remains the most effective way, especially in cases in which sampling points are randomly dispersed. However, these techniques have usually been used to elaborate maps of soil characteristics.

This work is the first study to assess the level of pollution in the Beni-Moussa irrigated perimeter. The research objectives are to:

- Carry out physico-chemical properties of the soil such as pH, OM, $CaCO_3$, and grain size.
- Doses the heavy metals concentrations and produce the spatial distribution maps (Cr, Cu, Zn, Pb, Fe, Ni, As and Cd).
- Assess the level of soil contamination using various indices (Igeo, EF, CF, and PLI), and potential ecological risk (PER).
- Determine the source of pollution in soils subject to an agricultural holding.
- Deduce the relationship between magnetic susceptibility (MS), and heavy metals.

Materials and methods

Study area

The Tadla plain is located approximately 200 km from Casablanca at an average altitude of 400 m and covers an area of about 3600 km^2 (Massont and Missante, 1966). This plain is crossed along its entire length by the Oum Er-Rbia River creates two independent irrigated perimeters: Beni-Moussa on the left bank and Beni-Amir on the right one. These areas are characterized by irrigated perimeters of 33.000 ha and 69.500 ha respectively (Hammoumi et al. 2013). The Tadla plain is characterized by a vast depression filled with quaternary deposits marle and limestone covered with red silt (Barakat et al. 2012). Our fields of study concern the soil of irrigated Beni-Moussa perimeter (Fig. 1).

Preparation of soil samples and chemical analysis

Twenty-five samples were taken from the upper soil layer (0–20 cm) in February 2017. Sampled points were distributed all over the study area to ensure appropriate spatial coverage of all agricultural lands, and samples were air-dried and screened to a diameter of 2 mm and then stored in a plastic bag at ambient temperature before analysis. The monitored quality parameters are pH, OM, $CaCo_3$, MS, grain size and heavy metal analysis.

- PH was measured in the soil solution (1/2.5) using a digital pH meter Hanna HI5521.
- The total organic matter was analyzed by combustion in the thermolyne oven (1200 °C) for 4 h at 550 °C.
- The calcium carbonate content $CaCO_3$ (%) was determined using Bernard calcimeter.
- The magnetic susceptibility was measured using a magnetic susceptibility meter, Bartington MS2B probe at frequencies (0.47 kHz–4.7 kHz). The high and low frequencies were measured, and the mean value is calculated (Suresh et al. 2011a).
- The particle size distribution was conducted using the Robinson pipette by settling after the dispersion of the elements with sodium Hexametaphosphate (Day 1965).

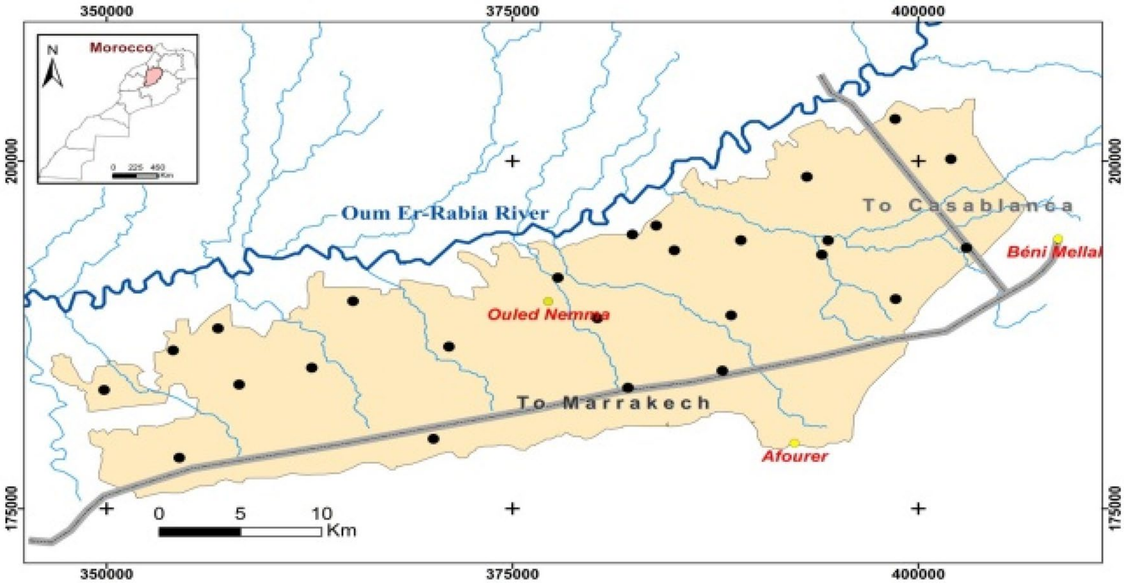

Fig.1 Location of the study area and sampling stations

- The heavy metal dosage was leached through an acid mixture (HNO3-HCl) which is added to the 10 g of the sample and heated to 110 °C until the solution became transparent (Allen et al. 1986). The solution was finally maintained at 100 ml using distilled water and stored at temperature room for the dosage of trace metal elements. The samples were then analyzed using an inductively coupled atomic plasma emission spectroscopy (ICP-AES) (Analyses Center at Beni Mellal Faculty of Science and Technology).

Drawing up spatial distribution maps (GIS)

The Kregeage method was used to develop spatial distribution maps of heavy metals. In our study, this interpolation method was performed by the Arc-GIS software with 25 samples to interpolate heavy metal concentrations.

Calculating pollution indices

To estimate the anthropogenic pollution by heavy metal in the studied area, we have calculated pollution indices such as a geo-accumulation index (Igeo), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI).

Geo-accumulation index (Igeo)

The estimation of the pollution that generally affects agricultural soils is generally done through the Igeo calculation (Parizanganeh et al. 2012; Mohamed et al. 2014; Kowalska et al. 2016), using the following equation:

$$\mathrm{Igeo} = \log 2 \frac{\mathrm{Cn}}{1.5 * \mathrm{Bn}}$$

where, Cn is the heavy metals content in the soil, Bn is the geochemical background levels of each element (n),

Table 1 Classes of the pollution indices Igeo by Müller (1969) EF by Sutherland (2000), and CF by Hakanson (1980)

Igeo value	Degree of pollution	EF value	Enrichment Degree	CF	Indication
≤ 0	Unpolluted	< 2	Minimum enrichment	< 1	Low contamination
0–1	Slightly polluted	2–5	Moderate enrichment	1–3	Moderate contamination factor
1–2	Moderately polluted	5–20	Important enrichment	3–6	Considerable contamination factor
2–3	Moderately severely polluted	20–40	Very large enrichment	> 6	Very high contamination factor
3–4	Severely polluted	≥ 40	Extremely large enrichment		
4–5	Extremely polluted				
> 5	Extremely polluted				

the constant 1.5 is used to analyze the natural fluctuation between substances in the environment and very weak anthropic influences. According to Muller (1969), I-geo was classified into seven grades (Table 1).

Enrichment factor (EF)

In this study, Fe is considered as a reference element as it is characterized by a low variability of occurrence. According to Daskalakis and O'Connor (1995), iron was selected as it is related to fine and these characteristics are analogous to that of many trace metals. The equation suggested by Zoller et al. (1974) was used to calculate the EF.

$$\mathrm{EF}=\frac{\left(\frac{\mathrm{C}}{\mathrm{Fe}}\right)\mathrm{sample}}{\left(\frac{\mathrm{C}}{\mathrm{Fe}}\right)\mathrm{Geochemical\ levels}}$$

where, (C/Fe) sample indicates the heavy metal level in the analyzed soil samples; (C/Fe) Geochemical background indicates the heavy metal content in the background levels. Five EF classes determined by Sutherland (2000) are shown in Table 1.

The pollution load index (PLI)

The pollution of Beni-Moussa soil was assessed and compared using the PLI by Tomlinson et al. (1980). This index is calculated from the amount of the concentration factors of every metal in the soil. The concentration factor is the report of the level of every metal in the soil of the natural concentration of the same metal. The latter was assimilated in our study to the median level of heavy metal in soils watered by groundwater. For each sampled site, the PLI is calculated as the nth root of the product of n concentration factors. The PLI above 1 symbolizes pollution.

$$\mathrm{PLI}=\sqrt[n]{\mathrm{CFi}\times\mathrm{CFj}\times\cdots\times\mathrm{CFn}}$$

where:

$$C_f^i=\frac{\text{Metal concentration } i}{\text{geochemical background of metal } i}$$

Three PLI classes were determined by (Tomlinson et al. 1980);

- PLI < 1 Clean soil
- PLI = 1 Pollutant level are present
- PLI > 1 Deterioration in the quality of the site.

Potential ecological risk index (PER)

The formula for calculating potential ecological risk index of each metal is as follows;

$$E_f^i=C_f^i * T_f^i$$

where, T_f^i is the response coefficient for the toxicity of every metal, the normalized response coefficient of heavy metal toxicity, which was proposed by Hakanson (1980).Was passed as assessment criteria; Hg = 40, Cd = 30, As = 10, Cu = Pb = Ni = 5,Cr = 2, Zn = 1. PER was widely used to evaluate the risk level of heavy metals in agricultural soil with the following equation;

$$\mathrm{PER}=\sum E_f^i$$

Standards Classification of Potential ecological risk index is given in Table 2.

Statistical analysis

Multivariate statistical analysis is widely used in environmental studies (Abubakr 2008; Lu et al. 2010; Anju and Banerjee 2012; Wang et al. 2012) to identify the relationship between heavy metals in soils and their possible sources. Pearson's correlation, principal component analysis (PCA), and cluster analysis (CA) were performed using SPSS Software. The correlation coefficient measures the association and interrelationship between two elements; PCA and CA are the most largely used methods for studying soil contamination.

Table 2 Standards Classification of Potential ecological risk index

Potential ecological risk index $\mathbf{E_f^i}$	Ecological risk index	Potential ecological index(PER)	Grades of potential ecological risk
< 40	Low	< 150	Low-grade
40–0	moderate	150–300	Moderate
80–160	Higher	300–600	Severe
160–320	Much higher	> 600	Serious
> 320	Serious		

PCA is used to excerpt a smaller number of independent factors from a large number of variables. This method has been used to determine pollution sources and to allocate the natural against anthropogenic contribution. PCA was carried out with varimax rotation with Kaiser Normalization in this research.

Cluster analysis (CA) was performed to arrange components of various sources based on the similitude of their proprieties. Hierarchical cluster analysis, utilized in this examination, aided in identifying relatively homogeneous groups of variables. That being with every variable in a different cluster and joins clusters until only one is left. A dendrogram was built to evaluate the cohesiveness of the shaped clusters, in which relationships between elements can be promptly seen.

Results and discussion

Soil properties

The results of the parameters which were measured on the samples are displayed in Table 3. PH is the first chemical parameter that controls the biological availability of metallic substances in farming soil (Brallier et al. 1996). The pH of the taken samples varies between 6.52 and 8.46. These values indicate that the pH of the soil is neutral to alkaline. These results can be related to the nature of the parent material which is calcareous conglomerates deposed from Beni Mellal High Atlas. The alkaline pH limits the passage of heavy metals from the solid state to soil solution and then to the plant (Thornton 1996) and can be considered as natural remediation of a high content of heavy metals. TOM and $CaCO_3$ content varies from 3.48 to 7.45% and from 6.6 to 56.6% with a medium of 5.37 and 21.41%, respectively. According to these results, the OM and $Caco_3$ are moderate to strongly high.

Table 3 Physicochemical parameters of agricultural soil at different stations in the Beni-Moussa area

Samples	PH/H2O	OM	CaCo3	% Sand	% Clay	% Silt	Xlf	Xhf	% FD
1	6.81	5.34	7.54	22.90	34.22	42.88	$2.41 * 10^{-4}$	$2.16 * 10^{-4}$	10.36
2	7.6	6.20	20.75	25.50	28.13	46.37	$2.78 * 10^{-4}$	$2.49 * 10^{-4}$	10.34
3	8.24	7.45	16.98	17.30	32.67	50.03	$2.91 * 10^{-4}$	$2.36 * 10^{-4}$	18.71
4	7.13	6.44	15.09	23.80	23.00	53.20	$1.09 * 10^{-4}$	$8.96 * 10^{-5}$	17.98
5	7.54	5.69	28.3	28.60	19.30	52.10	$1.24 * 10^{-4}$	$1.17 * 10^{-4}$	5.65
6	7.92	4.79	18.86	17.60	24.15	58.25	$2.51 * 10^{-4}$	$2.22 * 10^{-4}$	11.37
7	8.05	6.74	15.09	36.60	23.92	39.48	$9.16 * 10^{-5}$	$7.55 * 10^{-5}$	17.51
8	7.53	5.56	16.03	26.90	31.14	41.96	$2.63 * 10^{-5}$	$2.33 * 10^{-5}$	11.39
9	7.13	4.57	30.18	30.30	26.76	42.94	$1.46 * 10^{-5}$	$1.35 * 10^{-5}$	7.40
10	8.46	7.27	16.03	19.90	25.03	55.07	$2.75 * 10^{-4}$	$2.50 * 10^{-4}$	9.06
11	8.45	4.66	12.26	23.20	35.05	41.75	$2.62 * 10^{-4}$	$2.44 * 10^{-4}$	6.88
12	8	6.14	21.69	23.00	33.17	43.83	$1.31 * 10^{-4}$	$1.90 * 10^{-4}$	16.79
13	8.37	5.86	22.64	24.10	30.54	45.36	$1.43 * 10^{-4}$	$1.21 * 10^{-4}$	15.22
14	8.39	5.55	19.81	13.80	41.11	45.09	$1.20 * 10^{-4}$	$1.12 * 10^{-4}$	6.34
15	8.45	4.95	13.02	12.20	31.75	56.05	$2.09 * 10^{-4}$	$1.74 * 10^{-4}$	17.07
16	6.85	5.51	37.35	16.00	31.93	52.07	$1.31 * 10^{-4}$	$1.12 * 10^{-4}$	14.32
17	8.3	3.48	6.6	12.60	37.13	50.27	$3.08 * 10^{-4}$	$2.82 * 10^{-4}$	8.43
18	8.05	4.26	19.81	36.80	18.52	44.68	$1.27 * 10^{-4}$	$1.02 * 10^{-4}$	19.68
19	7.74	3.92	24.52	24.40	28.00	47.60	$2.37 * 10^{-4}$	$2.02 * 10^{-4}$	14.97
20	7.32	4.62	18.86	30.90	23.23	45.87	$2.01 * 10^{-4}$	$1.82 * 10^{-4}$	9.54
21	6.9	5.02	39.62	14.40	39.55	46.05	$3.00 * 10^{-4}$	$2.62 * 10^{-4}$	12.67
22	8.35	6.86	40.56	14.40	46.51	39.09	$1.74 * 10^{-5}$	$1.50 * 10^{-5}$	13.70
23	8.37	5.45	18.86	21.90	42.02	36.08	$5.71 * 10^{-5}$	$5.26 * 10^{-5}$	7.82
24	7.17	5.25	18.86	12.40	34.01	53.59	$1.19 * 10^{-4}$	$1.09 * 10^{-4}$	8.71
25	8.39	3.52	17.92	19.62	20.62	21.62	$1.81 * 10^{-4}$	$1.60 * 10^{-4}$	11.74
Min	6.52	3.48	6.6	12.20	18.52	21.62	$1.46 * 10^{-5}$	$1.35 * 10^{-5}$	5.64
Max	8.46	7.45	56.6	36.80	46.50	58.25	$3.08 * 10^{-4}$	$2.82 * 10^{-4}$	19.68
Average	7.80	5.37	21.41	21.96	30.46	46.05	$1.70 * 10^{-4}$	$1.49 * 10^{-4}$	12.14

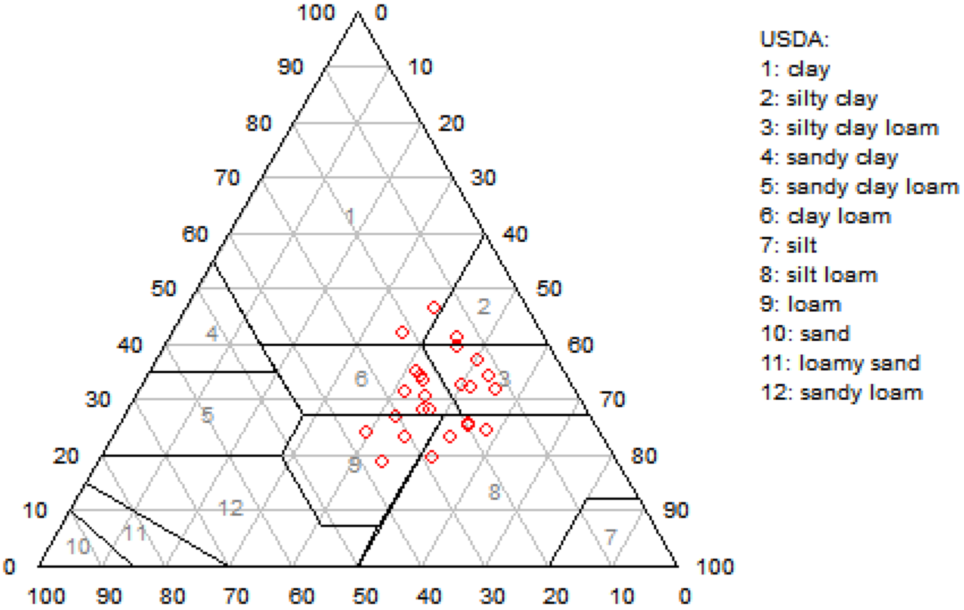

Fig.2 Soil texture triangle

Table 4 The texture classes of Beni Moussa soils in percentage

Class	%
Clay loam	27
Silty Clay loam	29
Silt loam	20
Loam	16
Clay	8

The texture of the soil is the percentage of granulometric distribution of sand, silt, and clay. The results of the grain size distribution of Beni-Moussa soils are displayed in Fig. 2. The percentage of sand is from 12.2 to 36.8% with a mean value of 21.96%, the silt varies from 21.62 to 58.25% with an average of 46.05%, and the clay varies from 18.52 to 46.50% with an average of 30.46%. However, the soil of Beni-Moussa can be reported to silty clay loam, clay loam, and silt loam as shown in the table of percentage (Table 4).

Heavy metals concentration in the studied zone

The metal trace elements of Beni-Moussa soil varies throughout the studied area. The results are given in Table 5. The average Cr value in soil samples is 28.34 mg/kg and ranges from 20.62 to 38.56 mg/kg. The average value of Cu and Zn is 45.99 mg/kg and 51.07 mg/kg with a range that varies between 38.58 and 52.65 mg/kg, 30.59 and 82.80 mg/kg, respectively. However, the mean value of Pb is 23.04 mg/kg ranges from 12.01 to 38.81 mg/kg. Fe is the major element in all sediment samples, ranging from 16,502.41 to 32,535.47 mg/kg with a means of 24,226.12 mg/kg. The average value of As, Cd, and Ni are 8.33 mg/kg, 0.83 mg/kg, 37.60 mg/kg with range varies between 4.2 and 12 mg/kg, 0.42 and 1.2 mg/kg, 28.5 and 48.05 mg/kg, respectively.

The average value of Pb and Zn in soil samples exceeds the FAO limit which is 5 mg/kg for Pb and 2 mg/kg for Zn. Fe values exceed the quality standards determined by the World Health Organization (WHO). Also, the value obtained from the Cu is above the standard value (30 mg/kg) recommended according to the United State Environmental Protection Agency. As, Ni and Cd concentrations are lower than the Canadian quality guidelines for agricultural soils and the Dutch intervention value (Table 6).

For a better assessment, the likely contamination in Beni-Moussa soil, the level of metallic pollutants should be compared with values reported from other areas in the world (Table 7). The average Cr and Zn concentrations are close to those obtained in Huizhou (China) (Cai et al. 2012). The Pb concentration is close to those found in Settat soils (Tomgouani et al. 2007). The Ni concentration is close to that obtained in Yangzhong (Huang et al. 2007).

Spatial dispersion of heavy metals

The distribution maps of the analyzed metals in the Beni-Moussa area (Cr, Cu, Pb, Zn, As, Cd, and Ni) are shown in Fig. 3. These maps have been prepared by the Kregage method using interpolated surfaces for better visualization of heavy metals distribution.

The spatial repartition of the Cr and Cu shows that the maximum concentrations are observed in the south-eastern and western part of the Beni-Moussa area. The minimal levels are located in the northern and central parts of the perimeter. These high concentrations coincide with the most cultivated areas where poultry farming is developing.

Table 5 Concentrations of heavy metals in agricultural soil in the Beni-Moussa perimeter in (mg/kg)

Samples	Cu	Pb	Zn	Cr	AS	Cd	Ni	Fe
1	46.69	38.81	48.88	27.51	7.79	0.779	34.05	25,764.18
2	47.66	24.96	49.44	29.27	10	1	38.69	22,811.41
3	47.4	23.36	50.29	30.47	8.34	0.834	39.74	27,290.15
4	50	14.7	54.67	32.55	7.34	0.734	28.5	19,699.09
5	41.89	30.51	44.95	24.52	7.97	0.797	39.89	22,905.29
6	43.01	36.78	46.2	27.09	10.5	1.05	38.44	19,027.11
7	39.5	38.68	43.32	21.89	9.93	0.993	28.83	19,339.18
8	40.65	32.21	30.59	23.54	8.41	0.841	32.39	23,523.14
9	43.6	17.41	47.38	24.42	5.95	0.595	34	20,364.9
10	52.65	17.65	56.95	34.5	8.51	0.851	43.91	28,327.31
11	52.33	19.26	82.8	35.68	6.79	0.679	48.05	28,288.65
12	47.11	30.85	52.45	30.4	5.56	0.556	40.69	24,766.73
13	48.5	19.2	55.79	30.85	8.92	0.892	39.22	25,022.95
14	47.98	31.45	49.56	28.87	9.71	0.971	35.15	28,064.03
15	48.87	15.01	50.54	31.17	11	1.1	41.23	31,584.45
16	50.66	13.4	57.16	33.06	8.65	0.865	46.24	25,780.2
17	50.21	19.91	54.36	32.04	9.6	0.96	40.35	32,433.42
18	42.22	24.4	47.71	38.56	12	1.2	47.43	21,906.43
19	48.12	20.87	55.23	25.36	8.04	0.804	32.11	21,726.19
20	47.94	15.3	52.74	29.13	6.57	0.657	37.52	21,094.5
21	46.76	20.79	55.08	28.77	5.97	0.597	37.32	24,306.36
22	38.58	19.84	45.07	20.62	6.44	0.644	29.47	19,204.37
23	39.32	12.01	44.69	21.81	4.2	0.42	36.99	16,502.41
24	41.31	20.01	48.43	23.74	11.1	1.11	37.9	24,569.49
25	46.82	18.7	52.67	22.62	9.02	0.902	31.78	24,934.92
Min	*38.58*	12.01	30.59	20.62	4.2	0.42	28.5	16,502.41
Max	*52.65*	38.81	82.8	38.56	12	1.2	48.05	32,433.42
Average	45.99	23.04	51.07	28.34	8.33	0.83	37.60	23,969.47

Table 6 Comparison of heavy metal concentrations with the existing standard

	As	Ni	Cd	Cr	Cu	Zn	Pb	Fe
CCME^{*1}	12	50	1.4	64	63	200	70	–
Dutch intervention value^{*2}	76	100	13	180	190	720	530	–
USEPA^{*3}	–	–	–	–	30	–	10	–
WHO	–	–	0.3	–	4	50	20	47.200
FAO	–	–	0.01	–	0.2	2.0	5	–
Present study	8.33	37.60	0.83	28.34	45.99	51.07	23.04	23,969.47

^{*1}Canadian soil quality guidelines for the Protection of Environment and Human Health. 2007

^{*2}VROM 2009

^{*3}United State Environmental Protection Agency

The increase in copper concentrations can be due to the use of fertilizers, sewage sludge, biocides and pesticides in agriculture, as well as the use of growth food (rich in Cu, Zn) by poultry farmers to ensure good growth. This means that a considerable quantity of metals is added to the soil during poultry litter (Asami et al. 1995; Dudka 1992).

Higher concentrations of Pb are found in the north-eastern part and southwestern part of the perimeter along the N8 national road that crosses the perimeter to Marrakech. These high concentrations are mainly due to the use of leaded gasoline while the lowest concentrations are located in Souk Sebt Ouled Nemma. The distribution map of Zn and Ni

Table 7 Comparative trace metal concentrations in the soils from China and Morocco

Location	As	Ni	Cd	Cr	Cu	Zn	Pb	References
Wuxi (China)	14.3	–	0.14	58 .6	40.4	112.9	46.7	Zhao et al. (2007)
Yangzhong	10.2	38.5	0.3	77.2	33.9	98.1	35.7	Huang et al. (2007)
Huizhou (China)	10.19	14.89	0.10	27.61	16.74	57.21	44.66	Cai et al. (2012)
Day River (Morocoo)	–	–	3.43	192.015	386.72	386.72	106.645	Barakat et al. (2012)
Tadla plain (Morocoo)	–	–	0.42	63.99	27.82	103.4	127.24	El Baghdadi et al. (2011)
Settat (Morocco)	3.56	5.16	0.26	5.25	10.91	20.12	29.66	Tomgouani et al. (2007)
Beni–Amir perimeter (Morocoo)	–	–	1.8	57.0	25.9	294.7	33.3	Oumenskou et al. (2018)
Beni-Moussa perimeter (Morocoo)	8.33	37.60	0.83	28.34	45.99	51.07	23.049	This study

demonstrates that the highest concentrations of these metals are located in the western part of the study area. They coincide with the area intensively cultivated with wheat and olive trees. This implies that the use of phosphate fertilizers that contain very high levels of Zn and Cd is responsible for the accumulation of these elements in the frequently cultivated soils. The higher concentrations of Cd and As are located in the eastern part of the perimeter, and they coincide with the areas irrigated with wastewater.

Geo-accumulation index (Igeo)

The Igeo calculation on the surface samples of the Beni-Moussa irrigated perimeter is included in Table 8. The Igeo value varies in the study area. It depends upon the presence or absence of metal contaminants in soil. The Igeo average values of Cu, Pb, Zn, Cr, As, Cd and Ni are below zero. This demonstrates that the majority of Beni-Moussa soil are unpolluted or lowly contaminated by these elements.

Enrichment factor (EF)

Fe was chosen as the reference element to calculate the EF of heavy metal. The Cu, Pb, Zn,Cr,As,Cd and Ni enrichment factors, are between 0.60 and 0.98, 0.18 and 0,75, 0.36 and 0.81, 0.44 and 0,85, 0.45 and 1.12, 0.32 and 0.79, 0.50 and 0.91 with average values of 0.75, 0.37, 0.60, 0.58,0.71,0.50,0.64 respectively. The EF values are less than 2, which show that the study area has a minimum enrichment with these metals. The levels of the studied metals are in the sequence listed Cu > As > Ni > Zn > Cr > Cd > Pb.

Contamination factor (CF)

The obtained results show that metals such as Cu, Zn, Cr, As, and Ni are above 1. This suggests that the soil in the studied perimeter is moderately contaminated with these metals. However, the Pb and Cd average values are below 1. This indicates low contamination with these metals. The soil is considered enriched when the CF average value is higher than 3.5 (Fernández and Carbaillera 2001), which affirms that the soil of Beni-Moussa agricultural sector is moderately contaminated with Cu, Zn, Cr, As, and Ni. According to the contamination factor values, the concentration of the studied metals are in the order of Cu > As > Ni > Zn > Cr > Cd > Pb.

Pollution load index (PLI)

The PLI of Beni-Moussa soil has been calculated to deduce the level of contamination. The PLI values below 1 do not signify any appreciable anthropogenic effects; whereas the PLI values above 1 indicate anthropogenic pollution (Tomlinson et al. 1980). The PLI values calculated for the Beni-Moussa soil are represented in Table 8. The PLI values are ranging from 0.78 and 1.33 with an average of 1.11. This indicates anthropogenic heavy metal contamination. The PLI spatial pattern demonstrates that the highest values are located in the East and South part of the study region. But the lowest values appear in the central part of the area under study (Fig. 4). The spatial repartition of the pollution index illustrates that the areas affected by anthropogenic pollution are located around Ouled Ayad, Had Bou Moussa, and Afourer.

Potential ecological risk (PER)

The potential risk evaluations of metal contamination in soils are presented in Table 9. According to this factor, the concentration of the studied metals is in the following order Cd > As > Cu > Ni > Pb > Cr > Zn. Cd is the largest one and its risk factor belongs to the middle grade in all the study areas. The PER value ranges from 38.85 to 84.88, with an average of 63.84. This indicates that the majority of the study area presents a low PER**.**

Magnetic susceptibility

Magnetic susceptibility (MS) can provide rich environmental reporting to quantify the anthropogenic metal charge in

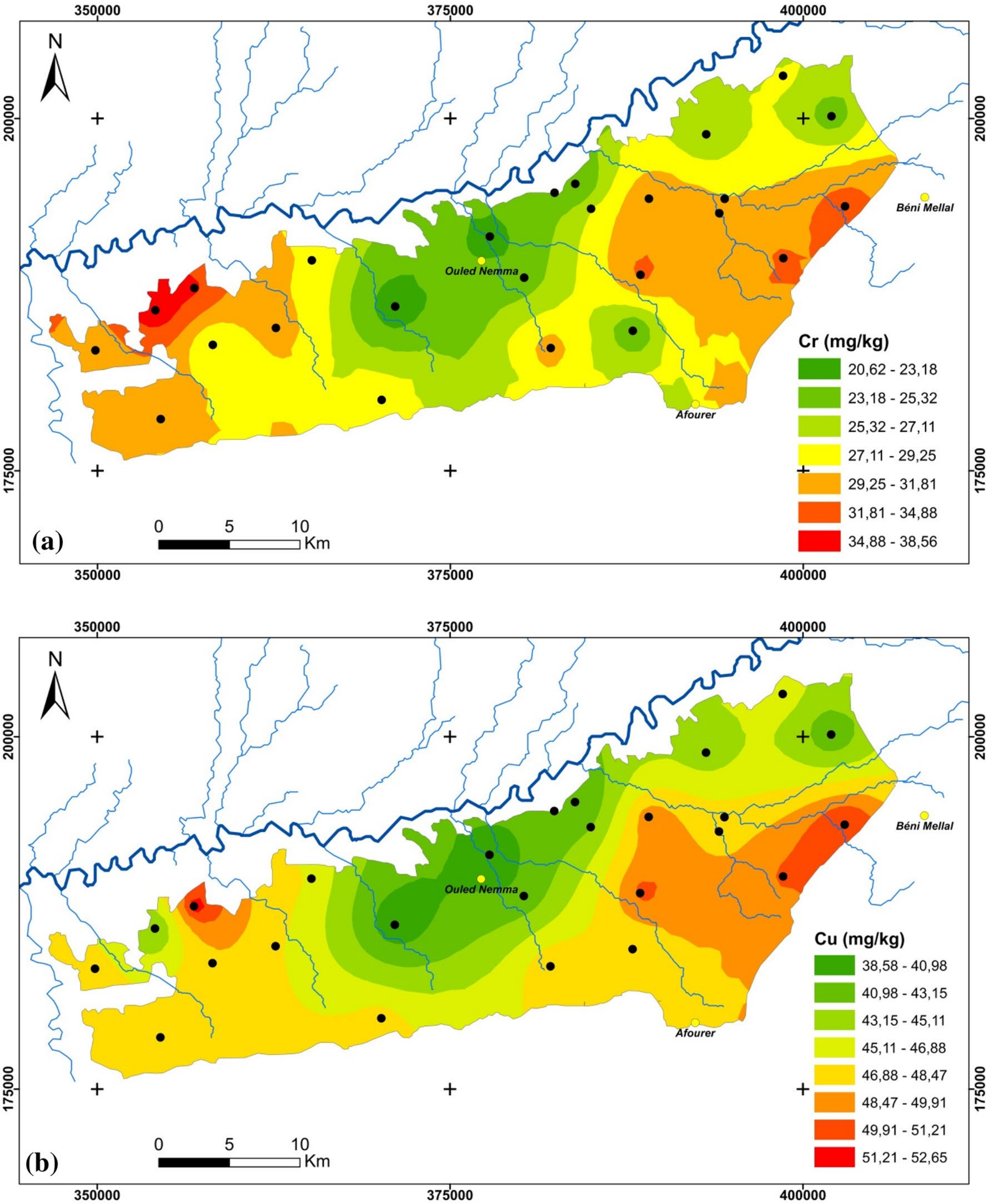

Fig.3 a, b, c, d, e, f, and g represent the spatial distribution maps of Cr, Cu, Pb, Zn, Ni, Cd, and As, respectively, in agricultural soil in the Beni-Moussa area

soil (Li and Feng 2012). Hanesch and Scholger (2002) suggested that anthropogenic anomalies would be defined, if the susceptibility difference surpassed 20.10^{-8}, and pedologic anomaly if it was under 20.10^{-8} m^3/kg. In this study, the value of low-frequency magnetic susceptibility (χLF) ranged from $3.08 * 10^{-4}$ and $1.46 * 10^{-5}m^3$/kg, with an average of $1.70 * 10^{-4}m^3$/kg (Table 3), which significantly higher than anthropogenic anomaly reference (20.10^{-8} m^3/kg).

Frequency-dependent susceptibility (χFD) is expected to reflect the meaningfulness of the grain size of the ferromagnetic phase, which is touchy to the nearness of the sub-micron sized grains, particularly those covering the super-paramagnetic (SP), and single domain (SD) limit

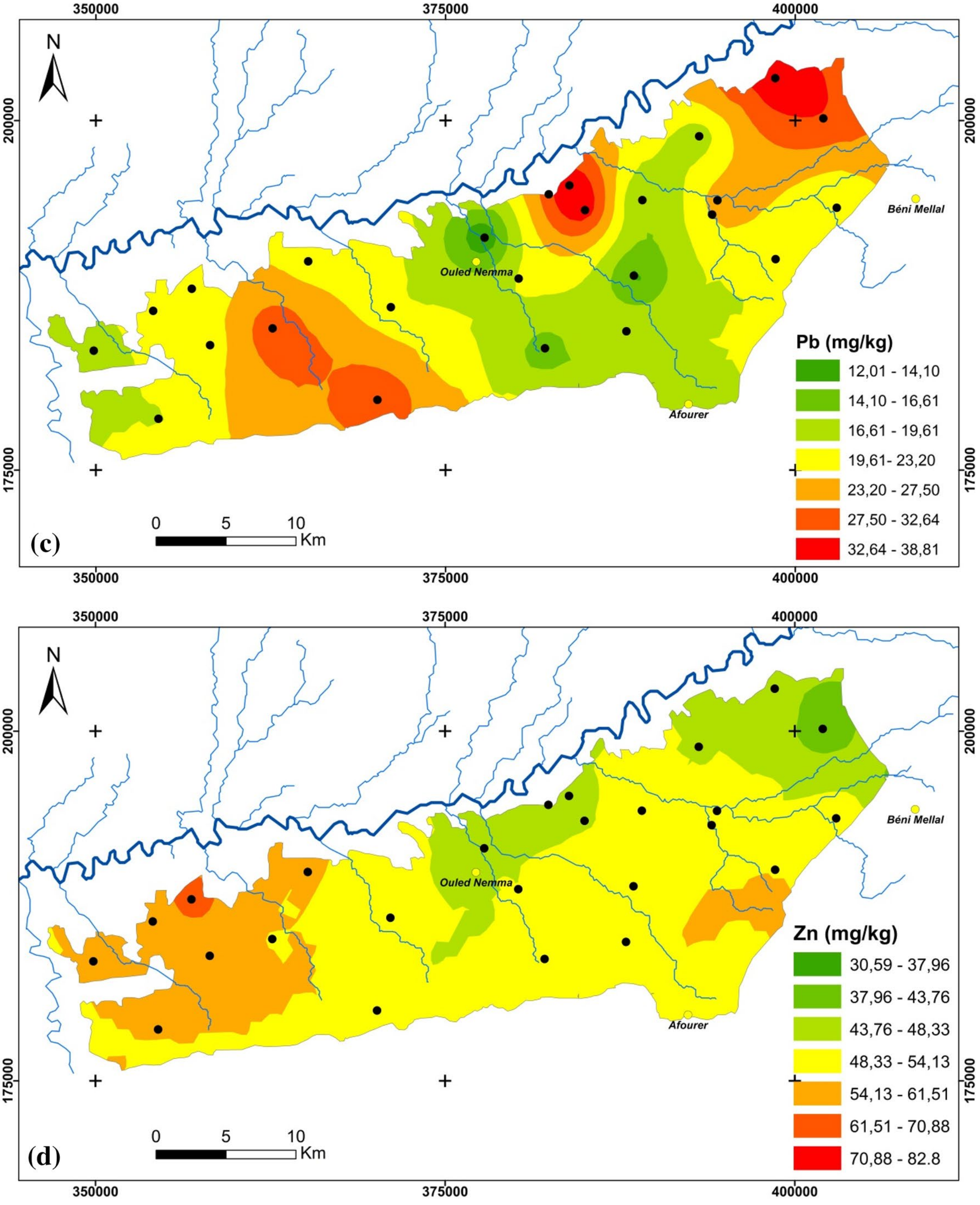

Fig.3 (continued)

(0.01–0.03) (Barbara et al. 1998). χFD can fill in as a marker of the particle origin, allowing us to recognize different sources. The χFD value of Beni-Moussa soils ranged from 5.64%, and 19.68%, an average 12.14%. χFD > 5% indicates a significant quantity of the ultrafine ferromagnetic mineral. These high values can suggest the existence of a relatively more super-paramagnetic (SP) magnetite of pedogenic-origin. Lecoanet et al. (2001) suggested that magnetic methods correspond not only to the level of ferromagnetic minerals but also their granulometric fraction, which allows discrimination of metallurgical dust and pedologic particles, their conclusion showed that contamination is not the only source and that pedogenesis process equally plays a role. Meng et al. (1997) has contested the presently dominant

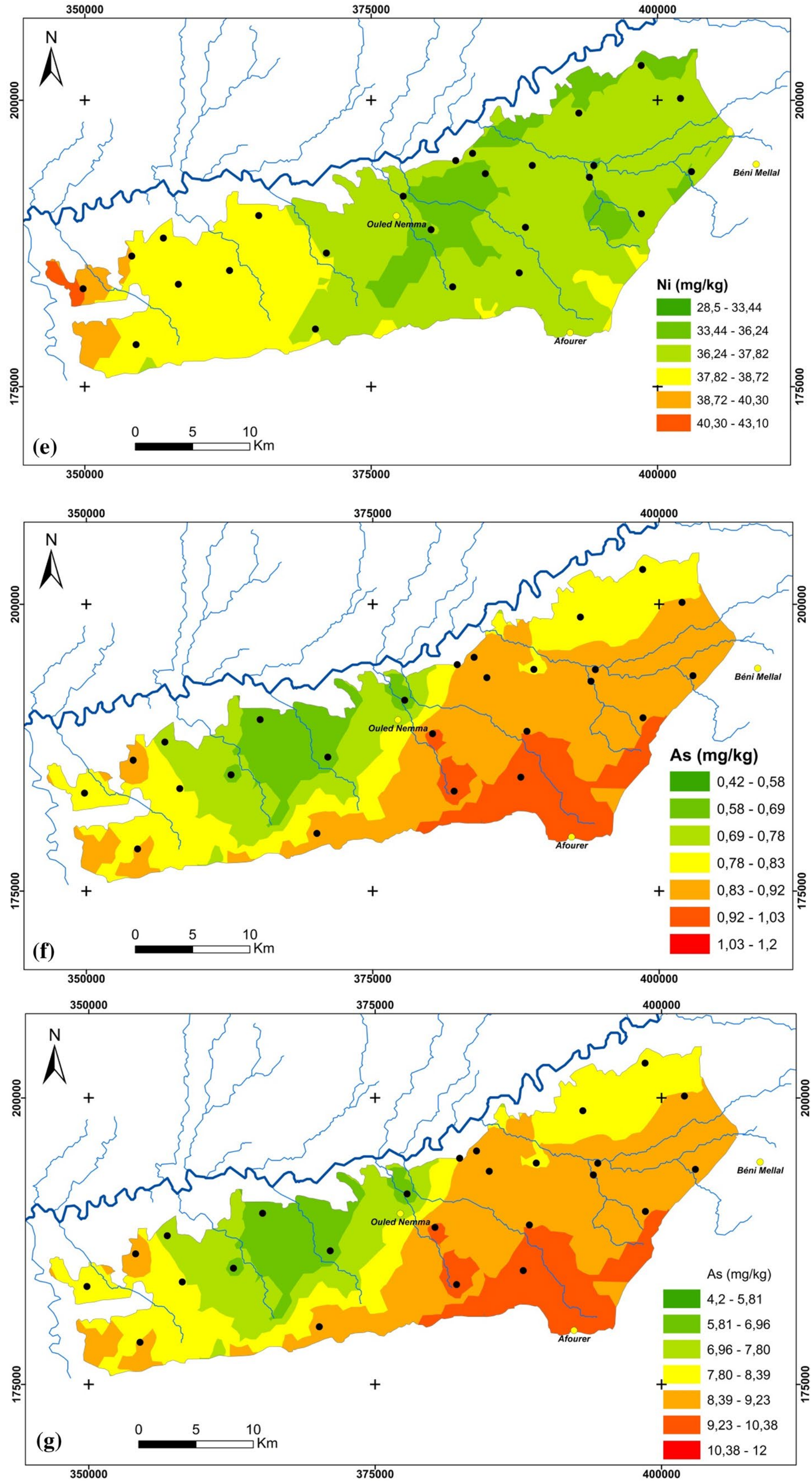

Fig.3 (continued)

Table 8 Pollution indices in agricultural soil in the Beni-Moussa region

	igeo							EF							CF							
Samples	Cu	Pb	Zn	Cr	As	Cd	Ni	Cu	Pb	Zn	Cr	As	Cd	Ni	Cu	Pb	Zn	Cr	As	Cd	Ni	PLI
1	− 0.01	− 0.33	− 0.43	− 0.47	− 0.21	− 0.71	− 0.40	0.70	0.56	0.53	0.51	0.61	0.43	0.53	1.49	1.19	1.12	1.09	1.30	0.92	1.14	1.17
2	0.02	− 0.97	− 0.41	− 0.46	0.15	− 0.35	− 0.22	0.81	0.41	0.60	0.62	0.89	0.63	0.69	1.52	0.77	1.13	1.16	1.67	1.18	1.29	1.21
3	0.01	− 1.06	− 0.38	− 0.57	− 0.11	− 0.61	− 0.18	0.67	0.32	0.51	0.54	0.62	0.44	0.59	1.51	0.72	1.15	1.21	1.39	0.98	1.32	1.15
4	0.09	− 1.73	− 0.26	− 0.57	− 0.29	− 0.80	− 0.66	0.98	0.28	0.77	0.80	0.75	0.53	0.59	1.59	0.45	1.25	1.29	1.22	0.86	0.95	1.02
5	− 0.17	− 0.68	− 0.55	− 0.84	− 0.18	− 0.68	− 0.17	0.71	0.50	0.54	0.52	0.70	0.50	0.70	1.33	0.94	1.03	0.97	1.33	0.94	1.33	1.11
6	− 0.13	− 0.41	− 0.51	− 0.79	0.22	− 0.28	− 0.23	0.87	0.72	0.67	0.69	1.12	0.79	0.82	1.37	1.13	1.06	1.07	1.75	1.24	1.28	1.25
7	− 0.25	− 0.34	− 0.60	− 1.11	0.14	− 0.36	− 0.64	0.79	0.75	0.62	0.55	1.04	0.73	0.60	1.26	1.19	0.99	0.87	1.66	1.17	0.96	1.13
8	− 0.21	− 0.60	− 1.10	− 1.11	− 0.10	− 0.60	− 0.47	0.67	0.51	0.36	0.48	0.72	0.51	0.56	1.29	0.99	0.70	0.93	1.40	0.99	1.08	1.03
9	− 0.11	− 1.49	− 0.47	− 1.92	− 0.60	− 1.10	− 0.40	0.83	0.32	0.65	0.58	0.59	0.42	0.68	1.39	0.54	1.08	0.97	0.99	0.70	1.13	0.93
10	0.16	− 1.47	− 0.20	− 0.50	− 0.08	− 0.58	− 0.04	0.72	0.23	0.56	0.59	0.61	0.43	0.63	1.68	0.54	1.30	1.37	1.42	1.00	1.46	1.19
11	0.15	− 1.34	0.34	0.34	− 0.41	− 0.91	0.09	0.72	0.25	0.81	0.61	0.49	0.34	0.69	1.67	0.59	1.89	1.42	1.13	0.80	1.60	1.21
12	0.00	− 0.66	− 0.32	− 0.29	− 0.69	− 1.20	− 0.15	0.74	0.46	0.59	0.59	0.45	0.32	0.66	1.50	0.95	1.20	1.21	0.93	0.65	1.36	1.08
13	0.04	− 1.35	− 0.23	− 0.20	− 0.01	− 0.52	− 0.20	0.75	0.29	0.62	0.59	0.72	0.51	0.63	1.54	0.59	1.27	1.22	1.49	1.05	1.31	1.16
14	0.03	− 0.63	− 0.41	− 0.19	0.11	− 0.39	− 0.36	0.66	0.42	0.49	0.50	0.70	0.49	0.51	1.53	0.97	1.13	1.15	1.62	1.14	1.17	1.23
15	0.05	− 1.70	− 0.38	− 0.99	0.29	− 0.21	− 0.13	0.60	0.18	0.44	0.48	0.70	0.50	0.53	1.56	0.46	1.15	1.24	1.83	1.29	1.37	1.19
16	0.11	− 1.86	− 0.20	− 0.28	− 0.06	− 0.56	0.04	0.76	0.19	0.62	0.62	0.68	0.48	0.73	1.61	0.41	1.31	1.31	1.44	1.02	1.54	1.14
17	0.09	− 1.29	− 0.27	− 0.36	0.09	− 0.41	− 0.16	0.60	0.23	0.47	0.48	0.60	0.42	0.50	1.60	0.61	1.24	1.27	1.60	1.13	1.35	1.21
18	− 0.16	− 1.00	− 0.46	− 1.04	0.42	− 0.09	0.08	0.75	0.42	0.60	0.85	1.11	0.78	0.88	1.34	0.75	1.09	1.53	2.00	1.41	1.58	1.33
19	0.03	− 1.23	− 0.25	− 0.24	− 0.16	− 0.67	− 0.49	0.86	0.36	0.71	0.56	0.75	0.53	0.60	1.53	0.64	1.26	1.01	1.34	0.95	1.07	1.08
20	0.03	− 1.67	− 0.32	− 0.39	− 0.45	− 0.96	− 0.26	0.88	0.27	0.69	0.67	0.63	0.44	0.72	1.53	0.47	1.21	1.16	1.10	0.77	1.25	1.01
21	− 0.01	− 1.23	− 0.25	− 0.35	− 0.59	− 1.09	− 0.27	0.74	0.32	0.63	0.57	0.50	0.35	0.62	1.49	0.64	1.26	1.14	1.00	0.70	1.24	1.02
22	− 0.29	− 1.30	− 0.54	− 0.79	− 0.48	− 0.99	− 0.61	0.78	0.39	0.65	0.52	0.68	0.48	0.62	1.23	0.61	1.03	0.82	1.07	0.76	0.98	0.91
23	− 0.26	− 2.02	− 0.55	− 1.18	− 1.10	− 1.60	− 0.28	0.92	0.27	0.75	0.64	0.52	0.36	0.91	1.25	0.37	1.02	0.87	0.70	0.49	1.23	0.78
24	− 0.19	− 1.29	− 0.44	− 0.95	0.30	− 0.20	− 0.25	0.65	0.30	0.55	0.47	0.91	0.65	0.62	1.32	0.61	1.11	0.94	1.85	1.31	1.26	1.14
25	− 0.01	− 1.38	− 0.32	− 0.53	0.00	− 0.50	− 0.50	0.73	0.28	0.59	0.44	0.73	0.52	0.52	1.49	0.57	1.20	0.90	1.50	1.06	1.06	1.07
Min	− 0.29	− 2.02	− 1.10	− 1.92	− 1.10	− 1.60	− 0.66	0.60	0.18	0.36	0.44	0.45	0.32	0.50	1.23	0.37	0.70	0.82	0.70	0.49	0.95	0.78
Max	0.16	− 0.33	0.34	0.34	0.42	− 0.09	0.09	0.98	0.75	0.81	0.85	1.12	0.79	0.91	1.68	1.19	1.89	1.53	2.00	1.41	1.60	1.33
Average	− 0.04	− 1.16	− 0.38	− 0.63	− 0.15	− 0.65	− 0.27	0.75	0.37	0.60	0.58	0.71	0.50	0.64	1.46	0.71	1.17	1.12	1.39	0.98	1.25	1.11

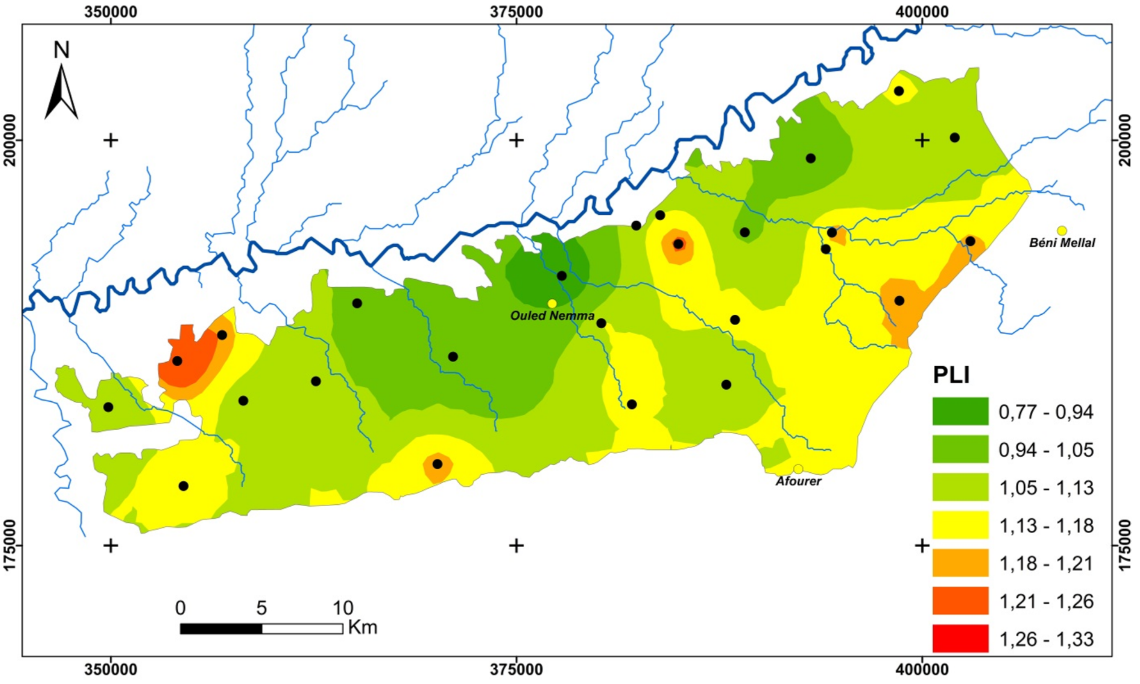

Fig.4 The spatial distribution of the pollution load index

pedogenic hypothesis and found that the decomposition of vegetation is an important source of the ultrafine magnetic minerals accountable for the magnetic susceptibility signal.

Pearson correlation

To deduce the inter-element relationship and identify the sources of soil pollution by determining the statistical correlation between physicochemical properties, pollution load index, potential ecological risk, heavy metal concentration, and magnetic susceptibility. The Pearson correlation coefficient for all elements was calculated and presented in Table 10. Pearson's correlation coefficient reveals that the Cr, Zn, Cu, Fe, and Ni are positively correlated among themselves. There is no correlation between Pb and other elements. As and Cd are positively correlated. Suresh et al. (2011b), and Çevik et al. (2009) proposed that the positive correlation between metals indicates that metals have a common source, but when they are not correlated, this indicates that their concentrations are not monitored by a single factor. As and Cd are positively correlated with PER (r = 0.987). This result confirms that the As and Cd content could create high ecological risk in soil. There are important positive correlations between χLF and heavy metal level, which is confirmed in several studies (Wang and Qin 2005; Morton et al. 2009; Yang et al. 2012). The correlation degrees between χLF and heavy metals were as follows: Cu > Fe > Zn. χLF is positively correlated with PLI (r = 0.525). This confirms that χLF may be used to deduce the degree of heavy metals contamination in agricultural soil. There is a poor and negative correlation between heavy metal and χFD which indicates that these elements are mainly originated from the anthropogenic inputs (Hu et al. 2007; Liu et al. 2016). Therefore, the eight studied metals of Beni Moussa perimeters are essentially generated by anthropogenic activities including industrial activities, agricultural practices and vehicles emission, which generate a large proportion of magnetic pollutant substances.

Given that there is a positive and significant correlation between PLI and χLF, soil metal contamination can be evaluated by soil χLF.With a view to establishing a classification of heavy metal contamination using magnetic susceptibility, we tried to make a regression and correlation between χLF and PLI. Then, linear regression was realized by using SPSS software (Fig. 5). The result shows the following regression equation:

$$\mathrm{PLI} = 0.08\chi\mathrm{LF} + 1$$

A correlation coefficient r = 0. 27 was obtained, which is larger than 0.01 level of the correlation coefficient, demonstrating a significant correlation between χLF and PLI.

The clay and sand are negatively correlated with studied metals, magnetic susceptibility, PLI, and PER, while silt content has a higher positive correlation with As, Cd, and PER. The Beni Moussa soils essentially have a silty

Table 9 Basic statistics of Potential Ecological Risk (PER) of soils

E_f^i								
Samples	Cu	Pb	Zn	Cr	As	Cd	Ni	PER
1	7.43	5.96	1.12	2.18	12.98	27.49	5.68	62.85
2	7.59	3.84	1.13	2.32	16.67	35.29	6.45	73.29
3	7.55	3.59	1.15	2.42	13.90	29.44	6.62	64.66
4	7.96	2.26	1.25	2.58	12.23	25.91	4.75	56.94
5	6.67	4.69	1.03	1.95	13.28	28.13	6.65	62.39
6	6.85	5.65	1.06	2.15	17.50	37.06	6.41	76.67
7	6.29	5.94	0.99	1.74	16.55	35.05	4.81	71.36
8	6.47	4.95	0.70	1.87	14.02	29.68	5.40	63.09
9	6.94	2.68	1.08	1.94	9.92	21.00	5.67	49.22
10	8.38	2.71	1.30	2.74	14.18	30.04	7.32	66.67
11	8.33	2.96	1.89	2.83	11.32	23.96	8.01	59.30
12	7.50	4.74	1.20	2.41	9.27	19.62	6.78	51.52
13	7.72	2.95	1.27	2.45	14.87	31.48	6.54	67.28
14	7.64	4.83	1.13	2.29	16.18	34.27	5.86	72.21
15	7.78	2.31	1.15	2.47	18.33	38.82	6.87	77.74
16	8.07	2.06	1.31	2.62	14.42	30.53	7.71	66.71
17	8.00	3.06	1.24	2.54	16.00	33.88	6.73	71.45
18	6.72	3.75	1.09	3.06	20.00	42.35	7.91	84.88
19	7.66	3.21	1.26	2.01	13.40	28.38	5.35	61.27
20	7.63	2.35	1.21	2.31	10.95	23.19	6.25	53.89
21	7.45	3.19	1.26	2.28	9.95	21.07	6.22	51.42
22	6.14	3.05	1.03	1.64	10.73	22.73	4.91	50.23
23	6.26	1.85	1.02	1.73	7.00	14.82	6.17	38.85
24	6.58	3.07	1.11	1.88	18.50	39.18	6.32	76.64
25	7.46	2.87	1.20	1.79	15.03	31.84	5.30	65.49
Min	6.14	1.85	0.70	1.64	7.00	14.82	4.75	38.85
Max	8.38	5.96	1.89	3.06	20.00	42.35	8.01	84.88
Average	7.32	3.54	1.17	2.25	13.89	29.41	6.27	63.84

texture with a high-cation exchange capacity, this fine fraction able to increase the content of heavy metals. No significant correlations were observed between heavy metals and pH, OM, $Caco_3$, and χFD for the analyzed soils.

Principal component analysis

PCA was applied to identify the sources of metallic pollutants. Tables 11, 12 present the factor loading after varimax rotation obtained by Kaiser Normalization and calculated by using SPSS software. Just as expected, six factors were obtained, accounting for 82.13% of the total variance. The relations among the elements based on the three-dimensional space (Fig. 6).

The first principal component (PC1) accounts for 25.08% of the variance and has high loadings of As, Cd, PLI, PER, and indicates that As, Cd, PER is highly meaningful to PLI. The second principal component (PC2) spanning the greatest amount of variance 23.09% includes Cu, Zn, Cr, Ni, Fe, and Ms. These indicate that the Cr, Ni, Cu, Zn, and Fe are responsible for magnetic susceptibility values. High loadings of these metals in this component factor source point to their anthropogenic origin. The third principal component (PC3) represents 11.19% of the variance, and highly positive loading of Fe, Clay, and negative loadings of sand. Principal components 4 (8.17% variance), 5 (7.54% variance), and 6 (7.03% of variance) contain Pb, PH, and OM, respectively.

Hierarchical cluster analysis

Figure 7 displays five clusters; (C1) As, Cd, PER, and PLI. (C2) Cr, Ni, Cu, Zn, Fe, MS, and silt. (C3) Pb. (C4) Sand, PH, OM, and X_{FD}. (C5) Clay and Caco3. Based on PCA and CA, three sources with corresponding cluster elements can be identified; (1) As and Cd have agricultural and domestic sources. (2) Cr, Ni, Cu, Zn, and Fe are mainly derived from agricultural and industrial sources. (3) Pb comes from traffic sources and wastewater irrigation. These results will be discussed in detail below;

Table 10 Pearson correlation coefficient

	Cu	Pb	Zn	Cr	As	Cd	Ni	Fe	PLI	PER	Sand	Silt	Clay	PH	OM	Caco3	MS	FD	LF	HF
Cu	1																			
Pb	− 0.343	1																		
Zn	0.734^{**}	− 0.391	1																	
Cr	0.711^{**}	− 0.217	0.582^{**}	1																
As	0.026	0.267	− 0.147	0.256	1															
Cd	0.026	0.267	− 0.147	0.256	1.000^{**}	1														
Ni	0.423^{*}	− 0.218	0.500^{*}	0.739^{**}	0.202	0.202	1													
Fe	0.661^{**}	− 0.082	0.404^{*}	0.509^{**}	0.334	0.334	0.482^{*}	1												
PLI	0.399^{*}	0.371	0.264	0.631^{**}	0.799^{**}	0.799^{**}	0.528^{**}	0.553^{**}	1											
PER	0.120	0.308	− 0.055	0.366	0.987^{**}	0.987^{**}	0.309	0.408^{*}	0.883^{**}	1										
Sand	− 0.280	0.258	− 0.175	0.004	− 0.052	− 0.052	− 0.084	-0.506^{**}	− 0.028	− 0.046	1									
Silt	0.414^{*}	− 0.139	0.118	0.274	0.509^{**}	0.509**	0.219	0.374	0.449^{*}	0.514^{**}	-0.409^{*}	1								
Clay	− 0.061	− 0.143	0.077	− 0.229	− 0.367	− 0.367	− 0.096	0.197	− 0.341	− 0.376	-0.661^{**}	-0.414^{*}	1							
PH	0.049	− 0.065	0.158	0.086	0.156	0.156	0.168	0.258	0.166	0.161	− 0.134	− 0.050	0.175	1						
OM	-0.094	0.156	− 0.178	− 0.033	− 0.137	− 0.137	-0.117	− 0.131	− 0.097	− 0.130	0.004	− 0.128	0.100	0.070	1					
Caco3	− 0.246	− 0.229	-0.088	− 0.238	− 0.327	− 0.327	− 0.058	− 0.361	− 0.386	− 0.360	− 0.095	− 0.127	0.200	− 0.301	0.132	1				
MS	0.649^{**}	0.011	0.515^{**}	0.476^{*}	0.199	0.199	0.401^{*}	0.540^{**}	0.523^{**}	0.287	− 0.308	0.429^{*}	− 0.045	0.077	− 0.166	− 0.324	1			
Xfd	0.000	0.009	− 0.100	0.250	0.234	0.234	− 0.074	− 0.088	0.154	0.219	0.157	0.065	− 0.210	0.057	0.253	0.042	− 0.053	1		
Xlf	0.647**	0.009	0.507**	0.481*	0.206	0.206	0.398*	0.537**	0.525**	0.292	− 0.306	0.434*	− 0. 0. 0.051	0.077	− 0.156	− 0.319	0.999**	0.678**	1	
Xhf	0.649**	0.013	0.523**	0. 0.469*	0.192	0.192	0.404*	0s.543**	0.520**	0.280	− 0. 0.310	0.422*	− 0.038	0.076	− 0.177	− 0.328	0.999**	0.668**	0.996**	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

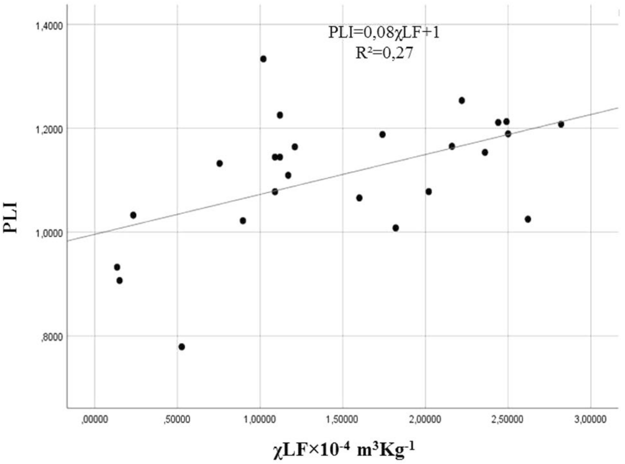

Fig.5 The scatter plot and regression equation between, χLF and PLI in Beni Moussa soil, Morocoo

The first group elements As and Cd, which represent a significant ecological risk are originated from common sources. The origin of Cd and As in Beni-Moussa soils is the application of agrochemical fertilizers, pesticides, herbicide, and phosphatic fertilizers which are a major source of As in agricultural land (Huang et al. 2007; Ahmed et al. 2014). To ensure the growth of livestock in Beni-Moussa, arsenic is used as a food additive. The use of these manures as organic fertilizers leads to an increase in its concentration in the soil (Sims and Wolf 1994).

The second group of elements, composed of Cr, Ni, Cu, Zn, and Fe has been identified as being those associated with agricultural and industrial activities. As the soils of the irrigated perimeters of Beni-Moussa are intensively cultivated with beetroot, wheat, potato, carrot, pea roots, olive trees, oranges, alfalfa, and sugar cane, the use of fertilizers is essential to ensure the growth of agricultural products. The uncontrolled use of fertilizers and waste from industrial units leads automatically to the concentration of metallic substances in the soil and the increasing accumulation of these elements leads to their migration to agricultural products that can be consumed by humans and animals (Bliefert and Perraud 2001).

One of the main sources of pollution in the Beni Moussa area is the Livestock and poultry intestine washing plant located in Ouled Moussa. Poultry litter, a mixture of excrement, feathers, waste, and water, animal feed and bedding are a precious by-product of the poultry production (Zhenbin and Larry 1997). Spreading poultry litter on cropland can promote metal mobility, because organic ligands soluble in poultry litter may form hydro soluble complexes with these metals (McBride 1989; Bolton and Evans 1991; Zhenbin and Larry 1997), which leads to the migration of these undesirable elements to the groundwater table and the deepest horizons of the soil, as great as the sugar factory located in Ouled Ayyad which processes either sugar beet or cane to produce granulated sugar and several by-products including bagasse, mill or filter sludge, mill effluents and waste. Bagasse is used as a power source, while waste and filter sludge are used as sources of nutrients and soil amendments (Yadav 2010). The continuous application of mill effluents at high rates without regard to soil conditions and crop needs have raised many concerns about over-fertilization and heavy metal (Liu and Chen 1991; Baruah et al. 1993; Abotal and Cabigon 2001) as well as off-site effects such as the impact on waterways.

The third group of elements consists of Pb is speared from the other elements in CA. This confirms that Pb has another anthropogenic source. Pb is considered as a label for circulation in the soil (Sabin et al. 2006). The area containing high levels of Pb is located along the road N°8 leading to Marrakech (El Baghdadi et al. 2011). Nevertheless, other areas far from road proximate to the same villages and which can be influenced by transport fumes, solid waste (El Baghdadi et al. 2015) and wastewater which is used for irrigation (Facchinelli et al.2001; Wong et al. 2002).

Table 11 Total explained variances

Component	Initial eigenvalues	Extraction sums of squared loadings	Rotation sums of squared loadings						
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%
1	5.828	32.380	32.380	5.828	32.380	32.380	4.515	25.083	25.083
2	3.404	18.912	51.292	3.404	18.912	51.292	4.158	23.099	48.182
3	1.810	10.058	61.350	1.810	10.058	61.350	2.016	11.198	59.380
4	1.385	7.692	69.042	1.385	7.692	69.042	1.472	8.176	67.556
5	1.329	7.384	76.426	1.329	7.384	76.426	1.358	7.547	75.103
6	1.027	5.707	82.133	1.027	5.707	82.133	1.265	7.030	82.133

Extraction method: principal component analysis

Table 12 Rotated component matrixes

Variables	Principal component						
	1	2	3	4	5	6	Communality
Cu	0.027	0.901	0.165	0.005	– 0.010	– 0.161	0.866
Pb	0.214	– 0.325	– 0.120	0.798	0.148	– 0.072	0.830
Zn	– 0.181	0.836	0.045	– 0.111	– 0.137	0.095	0.773
Cr	0.251	0.855	– 0.194	– 0.075	0.185	0.093	0.880
As	0.978	0.006	– 0.028	0.105	0.007	0.069	0.974
Cd	0.978	0.006	– 0.028	0.105	0.007	0.069	0.974
Ni	0.224	0.695	– 0.089	– 0.171	– 0.068	0.236	0.631
Fe	0.334	0.620	0.479	0.172	– 0.098	0.148	0.787
PLI	0.762	0.475	– 0.073	0.329	0.062	0.061	0.928
PER	0.962	0.128	– 0.043	0.170	0.021	0.071	0.978
Sand	– 0.113	– 0.150	– 0.947	0.172	0.044	0.052	0.967
Silt	0.626	0.302	0.224	– 0.175	– 0.070	– 0.469	0.789
Clay	– 0.402	– 0.099	0.761	– 0.028	0.013	0.334	0.863
PH	0.140	0.113	0.166	0.042	0.037	0.823	0.740
OM	– 0.177	– 0.096	0.122	0.161	0.834	0.012	0.777
Caco3	-0.257	– 0.257	0.094	– 0.607	0.204	– 0.254	0.616
MS	0.189	0.700	0.241	0.313	– 0.107	-0.207	0.735
FD	0.266	0.019	– 0.228	– 0.209	0.713	0.043	0.677
Eigenvalue percent of variance	25.08	23.09	11.19	8.17	7.54	7.03	
Cumulative percent	25.08	48.18	59.38	67.55	75.10	82.13	

Extraction method: principal component analysis; rotation method: Varimax with Kaiser Normalization. Rotation converged in seven iterations

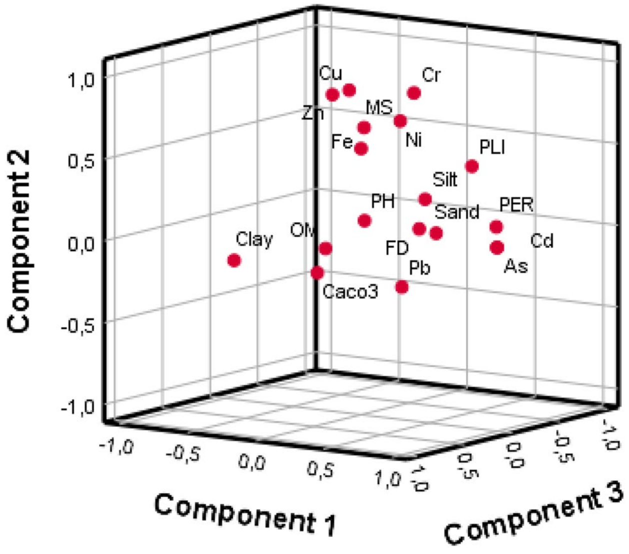

Fig. 6 Principal Component of the analysis results in the three-dimensional spaces showing loadings of the first three principal components

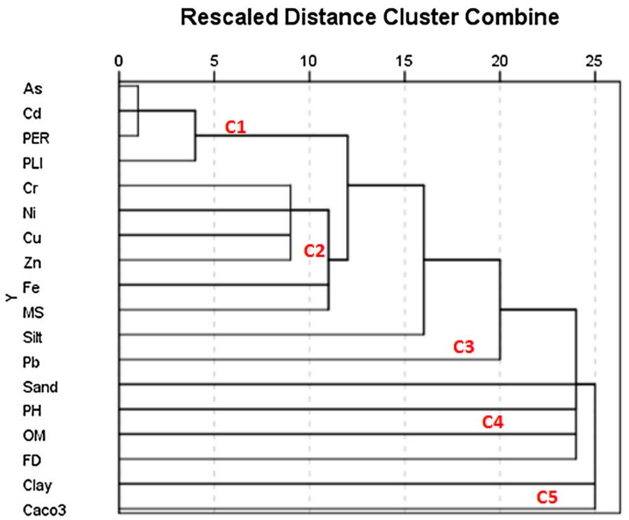

Fig. 7 Dendrogram demonstrating the cluster of variables based on similarity

Conclusion

Physico-chemical proprieties, spatial repartition of heavy metals (Cu, Pb, Zn, Cr, As, Cd, and Ni), granulometry and magnetic susceptibility were analyzed for Beni-Moussa soils. The obtained result suggests that;

I) The Beni-Moussa soil has an alkaline pH (that limits the mobility of heavy metals) is rich in organic matter and carbonate, has a silty texture and a very high magnetic susceptibility. These high susceptibility values are related to the strong mineralization well expressed in the different analyzed stations.

II) The pollution indices are very useful for raising environmental awareness, assessing environmental risks and soil deterioration, the obtained results of these indices revealed that the Beni Moussa soils are slightly contaminated by heavy metals. Pearson correlation coefficient indicates a positive correlation between Cr, Zn, Cu, Fe, and Ni, and a positive correlation between As and Cd. These positive correlations indicate that the heavy metals have a common or a similar source.

III) The spatial repartition maps of Pb show that the high concentrations are close to the N8 national road that crosses the study area leading to Marrakech and the area irrigated with wastewater, which confirms that the source of Pb is the transported dumps, the use of wastewater irrigation and agricultural equipment. Further, the high concentrations of (Cr, Ni, Cu, Zn, Fe, As, Cd) are coinciding with areas of intense human-anthropogenic activity; Sugar Plant, poultry intestines washing plant, and intensively cultivated land.

IV) Based on the measurements of the calculation of PLI and the correlation between χLF and PLI it may be deduced that; The χLF might be utilized to access the pollution degree by using the following equation: $\mathrm{PLI} = 0.08\mathrm{xlf} + 1$. It is important to note that this equation is valid only for the study area.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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