Assessment of heavy metal pollution in urban and peri-urban soil of Setif city (High Plains, eastern Algeria)

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Abstract Heavy metal pollution is a challenging concern that threatens the soil environment and human health worldwide. The purpose of this work is to assess the heavy metals (Cr, Cu, Zn, and Pb) pollution in the urban and peri-urban soils in and around Setif city, eastern Algeria. The work combines chemical analysis of thirty-six soil samples, statistical valuation and interpretation of chemical data and pollution indices (geoaccumulation index, pollution index, and integrated pollution index) with thematic mapping. The average concentrations (in mg/kg) of Cd, Cr, Cu, Pb, and Zn were found < 0.02, 43.35, 43.75, 331.20, and 78.26 mg/kg, respectively. Compared with the French regulatory limits (AFNOR U44-041), Cd, Cr, and Cu still non-hazardous at Setif city scale; however, Zn and Pb concentrations are two to three times higher than the background values referred to the Chinese B_n standard (GB15618-1995). The pollution indices indicate that Pb and Zn represent the highest threats among the studied pollutants and polluted wide areas of anthropogenic activities located respectively in the oldest district of the city, near the industrial zone and near uncontrolled landfill of domestic and industrial waste. Cu, Pb, and Zn originate seemly from vehicle emission, particles of brakes and tires, and industrial emissions. However, Cr distribution is uncorrelatable with anthropogenic sources. The Cr with an average concentration less than the background value derives seemly from animal feces and organic fertilizers. The integrated

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pollution index shows that the accumulation of heavy metals in the soils of Setif city from anthropogenic sources reached alarming levels that can disperse into the environment and threaten the human health. The urbanization and industrial development of Setif city are expected to grow and a subsequent heavy metal pollution will be rising prior issue. Corrective measures should be endeavored by the local authorities to mitigate the current environmental situation and a sustainable development plan for the city should be anticipated to guarantee optimal future environmental conditions.

Introduction

Soil contamination with heavy metals is a challenging concern that threatens plants, animals, and human health. These contaminants can accumulate in human body by direct transfer from air, water, soil and from food chain through plants uptake (Aelion et al., 2008; De Miguel et al., 2007; Poggio et al., 2008; Sebei et al., 2020; Sellami et al., 2020). The accumulation of non-biodegradable and non-thermo-degradable heavy metals in soils can engender dangerous levels of toxicity especially when these pollutants are long-term exposed to used waters (Kirpichtchikova et al., 2006; Sharma et al., 2008). Heavy metal contents in agricultural soils are generally compared to regulatory standards established for the most hazardous pollutants such lead (Pb), mercury (Hg), arsenic (As), cadmium (Cd), and nickel (Ni). The soil is considered polluted if the pollutant content is above the guideline value. In this case, the pollutant may present an ecological or health risks and the assessed area is considered polluted. When a given heavy metal become hazardous in an ecosystem, its concentration looks abnormally high relative to the geochemical background (Alloway & Ayres, 1997). For this reason, a good knowledge of the geochemical background is essential for evaluating heavy metal contamination in specific environmental settings.

Heavy metals are good convenient industrial materials and have been widely used in new technologies. Their worldwide demand and usages are extensive

and their introduction into the environment is rather recent (Turekian & Holland, 2003). Soil contamination by heavy metals comes mainly from mine and related industrial activities (metallurgical and steel industry, mine processes and tailings, chemistry, etc.), dissemination from fertilizers and pesticides used in agriculture and also from other nonneglected sources such waste incineration, medical waste, factory and combustion engine emissions, sewage effluents, sludge (Plumlee et al., 2003; Sukandar et al., 2006) and from residential heating and road traffic (catalyzed diesel vehicles). The contribution of these sources varies by country and environment type; however, according to many authors (e.g., Duzgoren-Aydin et al., 2006; Li et al., 2009; Morton-Bermea et al., 2009; Zhou et al., 2008), the main anthropogenic sources of heavy metals in the environment are the traffic, industrial and domestic emissions, building and pavement surfaces, and atmospheric deposition.

Since 1983, the Algerian state required an environmental impact assessment for some projects of development works and structures to evaluate their effects on the environment (Kerdoun, 2005). In fact, during the end of the twentieth century, the environmental pollution in Algeria was not a prominent matter of concern. Environmental studies focused on pollution assessment were devoted to some specific case studies related to main industrial projects. Since 2000, the Algerian state decided to invest in sustainable development as an attempt to mitigate the process of environmental degradation and meanwhile, the environmental pollution became a priority issue. This decision was made after Algeria accepted the international commitment which imposes in particular the change of some provisions in the Algerian legislation to agree the international conventions and protocols to which the country has acceded. Subsequently, a National Environmental Strategy (NSE) was adopted for the period 2001-2011. The NSE strategy gave emergence to two imposing tools: the law of the protection of the environment and the sustainable development promulgated in 2001, and the related national action plan NAPE-SD (Ouchene & Moroncini, 2018). Accordingly, studies devoted to environment and pollution in Algeria were significantly increased during the last decade. Water, air, and soil pollution was evaluated by researchers and authorities for many region and case studies in natural ecosystems and areas with anthropogenic activities such industry and agriculture.

This work is an attempt to evaluate the pollution by heavy metals (Cr, Cu, Zn, and Pb) of the urban and peri-urban soils in and around Setif city, eastern Algeria (Figs. 1 and 2). It combines chemical analysis of soil samples, statistical valuation of chemical data and pollution indices, and thematic mapping. The main sources of these heavy metals and the pollution risk they engender are discussed taking into account the natural and anthropogenic contexts and the urban development of the city.

Study area conditions

Urban and socio-economic development of Setif city: an overview

The city of Setif was broadly known since Classical antiquity as part of the ancient Berber kingdom of Numidia. It is located in eastern Algeria, south of Kabylie, at 270 km east of Algiers and at 131 km west of Constantine. Given this strategic location as crossroad city, it played the role of trade center and transit city to the Eastern Highlands since the Roman period. The contemporary history of the city began with the French colonization during the nineteenth century. At the beginning of the twentieth century, the city undergone significant urban expansion and count more than 26.000 habitants. In 1964, a master urban plan was established for the city in which some important constructions were managed (industrial zone, equipment zone, collective housing zone, bypass, and a boulevard around the city) with some rearrangement of the road network (O.T.H Algeria, 1971). Since 1966, an annual urban expansion of about 50 hectares was reported (Boudjenouia et al., 2006). Nowadays, the modern city was expanded around the ancient downtown to cover about 4000 hectares house of more than 300 thousand inhabitants. The main expansion was done toward the east due to the landscape configuration restricted by the wadi Boussalem toward the west.
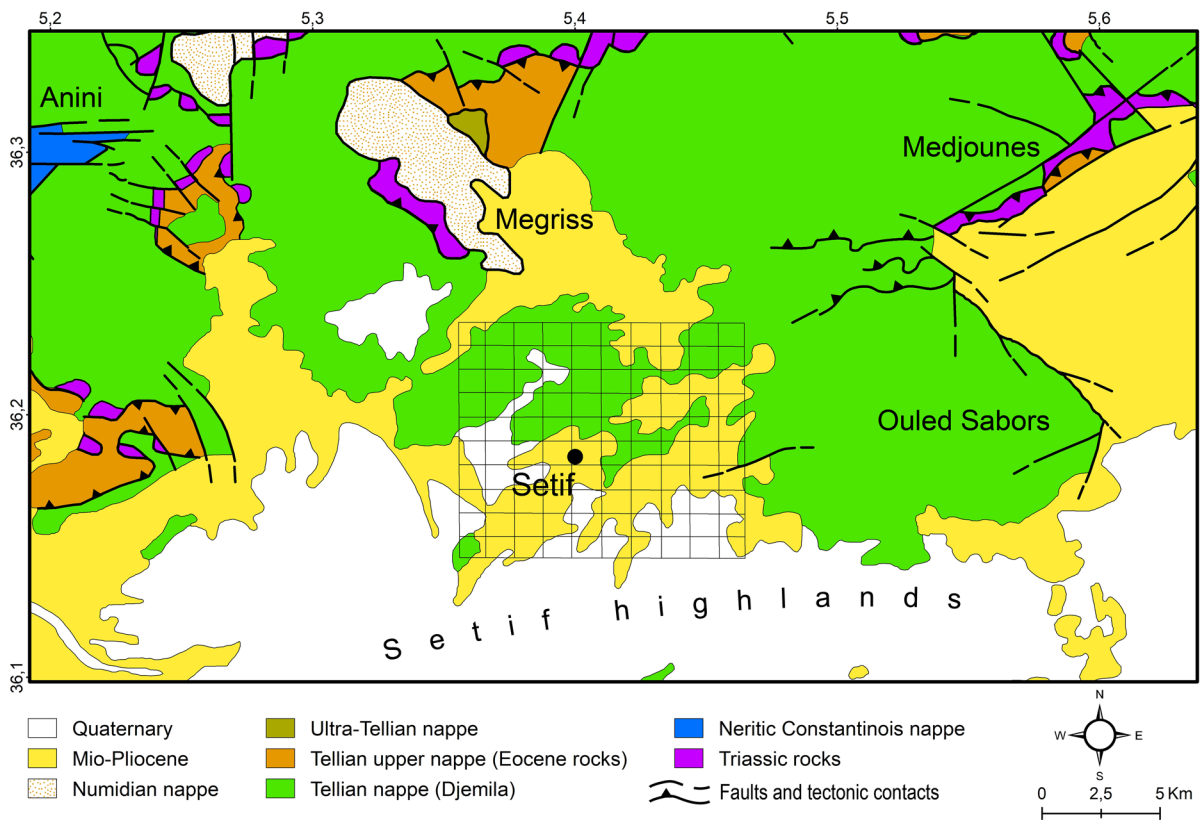
Fig. 1 Simplified geologic map of the of Setif city and its neighborhood. The grid locates the sampling area
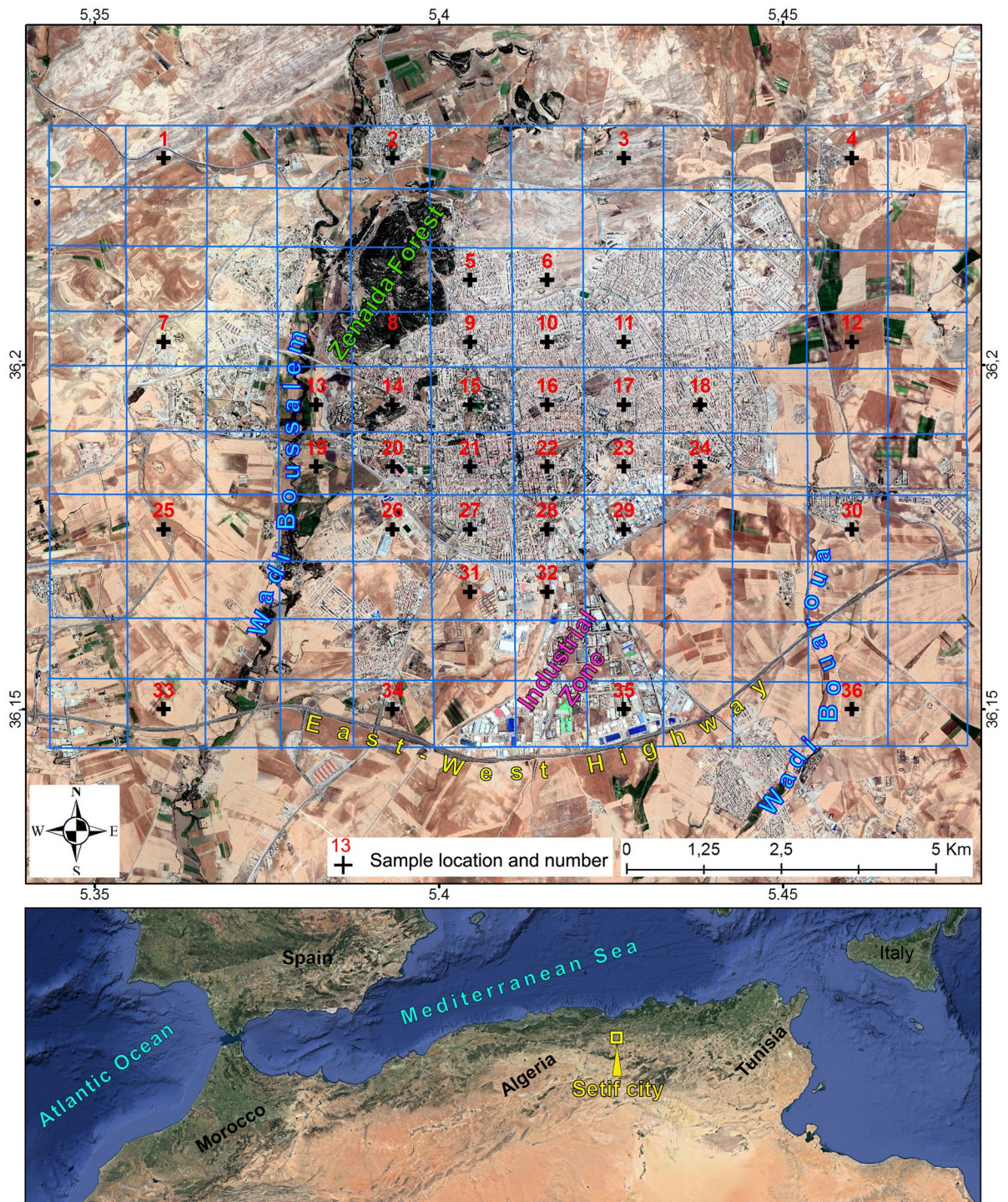
Fig. 2 Geographic location of the study area in the eastern Mediterranean region (bottom inset) and soil samples in Setif city (top map)

Economically, Setif is an attractive and dynamic economic and commercial metropolis in Algeria. It is also known as agricultural, industrial, touristic, and university pole. The main industrial activities are synthetic rubber and plastic processing, construction materials, and electronics industry (Sabah, 2016). The industrial zone southern the city fitted out on an area of 282 hectares in 1970 and encompasses today about hundred factories and workshops. Among these factories, the industrial groups of lead, electrolyte, batteries, and accumulators refining (ENPEC) and rubber-plastic processing (ENPC) occupy together more than 40 hectares with several industrial units. Urban and peri-urban agricultures are developed over wide areas of fertile soils around Setif city especially along the wadi Boussalem valley (Boudjenouia et al., 2006) where grain and livestock are key activities.

As crossroad city, Setif is well connected to the terrestrial Algerian road network including national and highway routes and it is also endowed by an urban railway and an international airport. Transport services in and via Setif city to ensure urban transport, trade and raw materials supply and goods delivery for and from the industrial zone, respectively, engender high traffic generating definitely significant atmospheric pollution.

Geography and landscape

Setif city extends nowadays between 5.35–5.45 DD longitudes and 36.13–36.24 DD latitudes in the Eastern Highlands of Algeria, at about 50 km south of the Mediterranean coastline and 217 km southeast of Algiers (Fig. 2). It is under a semi-arid climate characterized by a relatively temperate winter and a hot and dry summer with 400-mm annual rainfall. The annual average temperature is ~15 °C and the annual average potential evapotranspiration 1248 mm (Smadhi et al., 2002). Setif city culminate to about 1100 m and its peri-urban landscape is shaped by the mountainous reliefs and hills delimiting a watershed drained by a hydrographic network with a southwest general flow toward the wadi El Melah. The antique city was built along the plain laying between the wadi Boussalem to the west and the wadi Bouaroua to the east both are tributaries of wadi El Melah southward. Due to the urban expansion, the city overflowed the terrains outside these hydrographic limits. Natural

vegetation and some cultivated plots are fitted out along the wadi Boussalem; however, the upstream part of wadi Bouaroua was obliterated by the land development of the industrial zone to the south of the city and the wadi is regrettably home for urban and industrial pollution. About 192 hectares woody hill to the north of the city is preserved as forest heritage acknowledged as Zenaida forest.

Geology, hydrogeology, and soils resources

Setif city lays on a plain made of Mio-Plio-Quaternary rocks and surrounded by relatively ancient geologic bodies from Triassic to Cretaceous acknowledged as Tellian nappes locally overlaid by relic of flysch nappes both thrusting toward the south (Fig. 1, Vila, 1977). The aquifer system encompasses two types of hydrogeological formations; the Mio-Plio-Quaternary deposits made of conglomeratic and alluvium porous materials pumped for agricultural and domestic purpose, and the karstified and sandy carbonate formations with good reservoir quality enhanced by fractures (Djemmal et al., 2019). The soils in and around Setif city derive from the alteration of Tellian and flysch nappes rocks. They are mostly made of sands and clays. The most dominant minerals within these soils are kaolinite, illite, smectite, and chlorite (Djenba, 2013). Wide areas of Setif are covered by dark fertile soils acknowledged in Berber as "Zdif" from which derived the name of the region.

Materials and methods

Sampling and analytical procedures

Figure 3 shows the flowchart of the methodology we adopted in this work. Thirty-six soil surface samples (0–20 cm depth) were collected from Setif city and its close vicinity (Fig. 2) in spring 2015. The samples were collected at the center of 1×1 km squares chosen from a regular grid as follows: 20 samples were collected from the central part of the city according a 1×1 km grid to assess the content of studied elements expected as anthropogenic pollutants, and 16 samples were collected according a 4×4 km grid around the city in goal to detect if these pollutants are dispersed
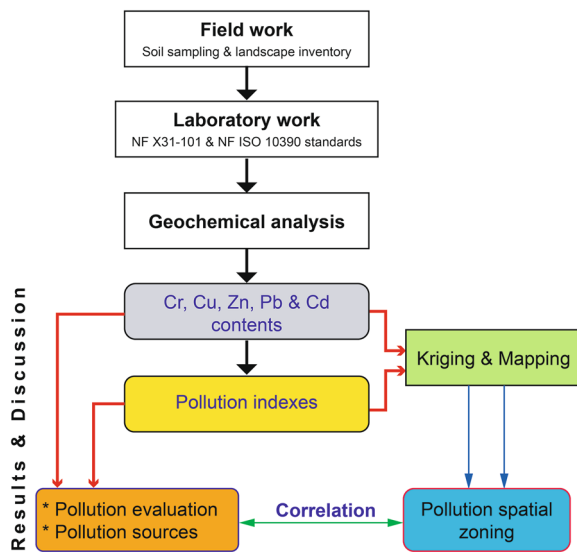
Fig. 3 Flow chart of the adopted methodology

Table 1 Soil pollution classes based on geoaccumulation index

Geoaccumulation index (I_{geo}) value	Soil pollution class
<1	Unpolluted
$1 < I_{geo} < 3$	Very low to low polluted
$3 < I_{geo} < 4$	Moderately polluted
$4 < I_{geo} < 5$	Highly polluted
$5 < I_{geo} < 6$	Very highly polluted

out of the urban zone. The location of samples was defined using GPS device. When the estimated location is occupied by construction or pavement surface, the sample is taken from the closest available soil outcrop. Randomly, some samples (e.g., 2, 4, 7, and 30) fall in new marginal urban areas or in the industrial zone (sample 35). These samples will be indicative for further in situ urban pollution outside the oldest city.

The samples were dried in open air then sieved through a 2-mm sieve according to the NF X31-101 standards (AFNOR, 1992). Then they were digested by the aqua regia method using a mixture of nitric acid (65%) and hydrochloric acid (37%). The Cr, Cu, Zn, Pb, and Cd concentrations were measured by furnace atomic absorption spectrometry using Analytik Jena NovAA 400 instrument.

The pH values of samples were measured in water with a 1:5 soil water according to the NF ISO 10390 standards (AFNOR, 2005) using a digital pH-meter (Cyber Scan pH 510). Ten grams of each sample were placed into a clean beaker with 25 ml of deionized water then stirred for 30 min. The pH-meter was calibrated using standard buffer solutions and measurements were done by immersing the calibrated probes in the upper part of the stirred mixture until the stabilization of reading (Edokpayi et al., 2018).

Spatial evaluation of soil contamination

The spatial distribution of the studied heavy metal in the urban and peri-urban soils of Setif was evaluated using thematic mapping based on the interpolation of local measured values of pollutant concentrations by applying the geostatistical technique of kriging using Golden Software Surfer 16. The soil contamination levels with heavy metals were estimated using the following pollution indices: geoaccumulation index (I_{geo}), pollution index (*PI*), and integrated pollution index (*IPI*).

Geoaccumulation index

Müller (1979) introduced originally the I_{geo} to evaluate the concentration of a metal n within the <2 µm fraction of a soil sample using the following formula:

$$I_{geo} = log_2\left(\frac{C_n}{1.5B_n}\right)$$

C_n is the measured concentration (mg/kg) of the metal n, B_n is the background concentration (in mg/kg) of the metal n, and 1.5 is a factor used to include possible variation of background values due to lithogenic effects (Müller, 1979) or anthropogenic influences (Malkoc et al., 2010). The formula was later extended by researchers to metal concentrations in <63 µm fraction and to regional background values (Belzunce et al., 2004). In this study, the background values of the studied elements are not defined for Setif city. Alternatively, we used the Chinese B_n standard GB15618-1995 provided by the Chinese Environmental Protection Administration (CEPA, 1995).

Müller ([1979](#)) proposed the following classes of pollution based on the I_{geo}: unpolluted ($I_{geo} < 1$), very low and low polluted ($1 < I_{geo} < 3$), moderately polluted ($3 < I_{geo} < 4$), highly polluted ($4 < I_{geo} < 5$), and very highly polluted ($5 < I_{geo} < 6$) (Table 1). I_{geo} has been widely used in Europe since the late 1960s for the evaluation of soil pollution by heavy metals (Blomberg, [2007](#); Iya et al., [2018](#)).

Pollution index and integrated pollution index

The *PI* and the *IPI* pollution indices are commonly used to describe the environment quality (Malkoc et al., [2010](#); Faiz et al., [2009](#); Lu et al., [2009](#)). *PI* of a given metal is defined as the ratio of C_n to B_n defined above, using the following formula:

$$PI = \frac{C_n}{B_n}$$

The *PI* of a given metal is classified into low ($PI \leq 1$), middle ($1 < PI \leq 3$), and high ($PI > 3$) (Faiz et al., [2009](#)). In this study, we refer to the soil background values of Sichuan Province (China) for Cr, Cu, Pb, and Zn, which are 61.0, 22.6, 26.0, and 100.0 mg/kg, respectively (Harikumar & Jisha, [2010](#)).

The *IPI* is defined as the average value of the computed *PI* of *n* considered elements (1, 2, 3, …, *n*) and it is calculated using the following formula (Li et al., [2009](#); Liu et al., [2006](#); Muller, [1969](#)):

$$IPI = (IP_1 \times IP_2 \times IP_3 \cdots \times IP_n)^{\frac{1}{n}}$$

Based on this pollution criteria, soils are evaluated as low contaminated soils ($IPI \leq 1$), moderate contaminated soils ($1 < IPI < 2$), or high contaminated soils ($IPI > 2$) (Table 2).

Table 2 Soil contamination classes based on the integrated pollution index

Integrated pollution index (*IPI*) value	Soil pollution class
$IPI \leq 1$	Low contaminated
$1 < IPI < 2$	Moderately contaminated
$IPI > 2$	Highly contaminated

Results and discussion

Spatial distribution and potential sources of heavy metals

The concentrations of Cr, Cu, Zn, and Pb (in mg/kg) in the soils of Setif city were found in the range of 10.85–99.98, 25.99–77.25, 78.95–632.5, and 24.09–383.62, respectively (Table 3). Their spatial variations are shown using four respective maps in Fig. 4 established using Surfer software. These maps illustrate proportional symbol sizes drawn at the sample's locations together with interpolated iso-concentration contours. For each element, the iso-concentration contours are drawn in green when the concentration values are less than the regulatory limit, and in red for the values above this limit. Therefore, in Fig. 4 the areas underlined with green contours are considered unpolluted and areas with red contours are thus polluted. The black contour in Fig. 4c, d matches with the regulatory limits (respectively of Zn and Pb) and makes the approximate limit between polluted and unpolluted zones. The quick visual analysis of these maps points out that Cr and Cu (Fig. 4a, b) are not hazardous in the study area, however, Zn and Pb (Fig. 4c, d) exceed their regulatory limits in wide areas of the city and cumulates both almost in the same localities. The most polluted zones by these two elements are the oldest district in the downtown (around the samples 20 and 21), the industrial zone (around sample 32), and the eastern side of the city where uncontrolled landfill of domestic and industrial waste are highlighted near sample 30. The pollution engendered by Zn is also highlighted in the northern side of the city around samples 2 and 5. There is an evident correlation between the increase of Cu, Pb, and Zn concentrations and these elements seem cumulate by anthropogenic input such atmospheric emissions and domestic and industrial wastes. High levels of Pb in urban soils have been reported to be associated with vehicle exhaust resulting from the use of lead gasoline (De Miguel et al., [1997](#); Imperato et al., [2003](#); Saby et al., [2006](#)). Cu has been used in vehicle braking systems and automatic radiators in Setif (Guo et al., [2012](#); Miner, [1993](#)). In addition to industrial activities, vehicle emissions can contribute to significant accumulation of Pb in the roadside soil of Setif. The fact that the central part of the

Table 3 Chemical analysis for Cr, Cu, Zn, and Pb concentrations and pH of 36 geolocated soil samples from Setif city, Algeria, with background values referred to the Chinese B_n standard GB15618-1995 and the French regulatory limits referred to AFNOR U44-041 standards

Sample number	Coordinates (DD)		pH	Cr (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)
	Y	X					
01	5,360	36,185	8.18	29.05	25.99	78.95	43.59
02	5,393	36,185	8.07	69.12	51.40	455.50	88.97
03	5,427	36,185	8.30	19.40	29.65	106.10	40.30
04	5,460	36,185	8.08	71.78	62.87	374.80	101.62
05	5,405	36,167	8.38	34.83	43.18	422.50	55.71
06	5,416	36,167	8.06	48.65	41.28	325.90	121.93
07	5,360	36,158	8.47	10.85	26.95	190.40	30.76
08	5,393	36,158	8.34	85.38	41.66	294.80	51.70
09	5,405	36,158	7.92	45.06	37.52	128.80	31.43
10	5,416	36,158	8.03	59.57	51.54	288.50	66.83
11	5,427	36,158	8.00	29.87	39.94	167.10	33.23
12	5,460	36,158	8.09	99.98	56.22	382.40	51.18
13	5,382	36,150	8.01	42.79	39.58	387.90	24.09
14	5,393	36,150	7.96	89.71	38.22	478.10	54.62
15	5,405	36,150	7.98	27.45	53.70	372.50	79.08
16	5,416	36,150	8.08	59.84	45.87	351.90	46.49
17	5,427	36,150	8.00	54.86	52.24	344.10	33.23
18	5,438	36,150	8.17	45.92	47.82	360.50	47.65
19	5,382	36,230	8.14	37.58	44.36	402.50	26.93
20	5,393	36,230	7.75	55.43	52.80	513.20	176.40
21	5,405	36,230	7.81	41.34	77.25	632.50	218.30
22	5,416	36,230	8.00	47.39	50.29	407.80	45.98
23	5,427	36,230	8.04	29.63	36.71	269.40	66.82
24	5,438	36,230	7.84	35.64	38.98	334.20	114.50
25	5,360	36,221	8.18	36.71	34.25	168.90	31.07
26	5,393	36,221	8.36	40.85	43.89	307.60	38.45
27	5,405	36,221	7.75	36.23	50.94	498.20	80.26
28	5,416	36,221	8.27	15.58	44.42	288.20	52.88
29	5,427	36,221	8.38	23.09	46.26	256.10	58.54
30	5,460	36,221	8.21	48.71	75.58	556.50	170.50
31	5,405	36,212	7.78	30.85	34.43	302.90	106.70
32	5,416	36,212	8.12	18.64	33.77	585.50	383.62
33	5,360	36,194	8.14	36.55	33.52	194.80	28.89
34	5,393	36,194	8.17	41.83	26.99	175.70	71.75
35	5,427	36,194	8.11	39.39	31.72	297.90	29.14
36	5,460	36,194	8.26	21.11	33.49	221.10	114.15
Average value			8.09	43.35	8.09	331.21	78.25
Background value				61	22.6	100	26
Regulatory limit				150	100	300	100

city is the oldest district increased the duration of its exposition to the anthropogenic sources of pollution which cumulated significant concentration of heavy metal. The spatial distribution of Cr (Fig. 4a)

is unlike those of Cu, Pb, and Zn. Firstly, concentrations are under the regulatory limits, and secondly, the highest ones are located near the Zenaida forest, peri-urban cultivated soil, and Setif zoo where
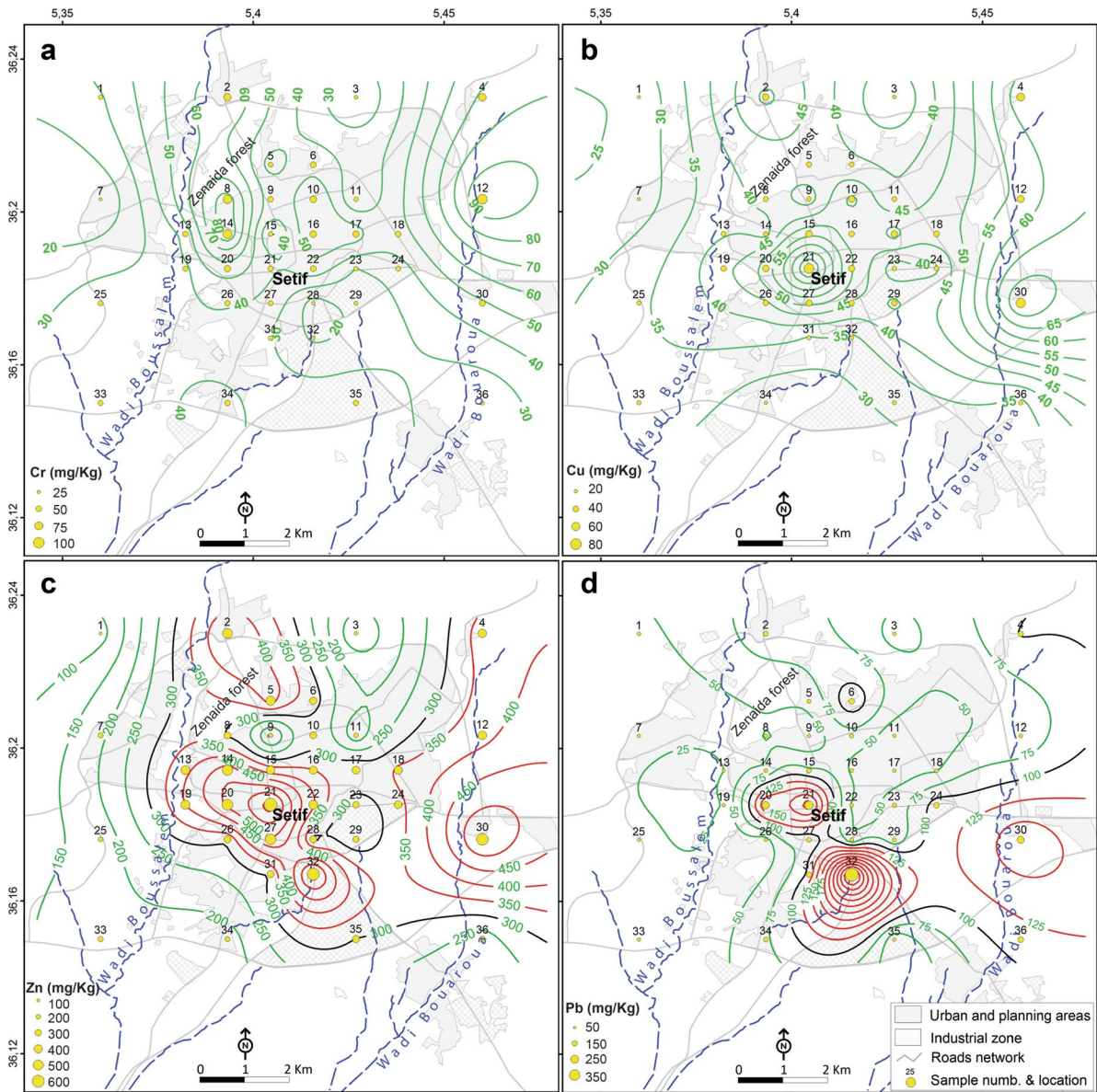
Fig. 4 Maps of the spatial variation of Cr, Cu, Zn, and Pb concentrations in Setif city soils using proportional symbol sizes and interpolated iso-concentration contours. Iso-concentration contour color explanation: green: concentration < regulatory limit, red: concentration > regulatory limit, black: concentration = regulatory limit

anthropogenic activities are much fewer. In contrast, these areas are home of forest and agricultural soils with animals and plants actions. As stated above, the Cr enrichment here is not linked to traffic and industrial activities. It derives from animal feces and organic fertilizers.

The average Cr, Cu, Zn, and Pb concentrations values are 43.35, 43.75, 331.21, and 78.25,

respectively. The Cd concentrations (not represented in Table 1) were found below 0.02 mg/kg and they still much lower than the AFNOR U44-041 admissible limit of 2 mg/kg. This is why cadmium is not considered until now an alarming environmental issue in Setif city. Among the four studied elements, only Cr shows an average concentration less than the background value. However, Cu, Zn, and Pb are

two to three times more concentrated than the background values.

Cr can be released to soil by natural alteration of chromite minerals (Ertani et al., 2017) and by anthropogenic activities such as chromium plating, metal finishing, leather tanning, and paint production (Chrysochoou et al., 2016). In Setif city, there is no evident correlation between Cr concentration and industrial activities since the detected values near the industrial zone (sample 32) where two leather tanning are inventoried and the oldest city (sample 28) occupy the second and third rank of the lowest values. However, the highest concentrations of Cr were detected within samples 8, 12, and 14. This local chromium enrichment occurred in the Zenaida forest, peri-urban cultivated soil, and Setif zoo respectively, which argue to the fact that Cr derived seemly from animal feces and organic fertilizers acknowledged as sources of Cr for soils (INERIS, 2014).

Cu average concentration is 43.75 mg/kg and it is similar to that highlighted within Spanish soils (Navas & Machín, 2002). The main anthropogenic sources of Cu to soils are atmospheric input, mining activities, local industrial contamination, and agricultural practices such the usage of fertilizers, pesticides, and sewage sludge. In Setif city, the highest concentration was detected within sample 21 (77.25 mg/kg) in the oldest district which privileges the atmospheric input and particles from car brakes as main source of Cu in Setif city.

The geochemical results show an evident correlation between Pb and Zn concentrations since the highest concentrations of these two elements were detected, at a time, for the same samples (e.g., 20, 21, 30, and 32, Table 1). Samples 20 and 21 are located in the oldest district, sample 32 is in the industrial zone entry, and sample 30 was taken near an uncontrolled landfill of domestic and industrial waste. It appears that these pollutants derive from anthropogenic origins such traffic, vehicle emission, particles from brakes and tires, and local industrial zone. The contaminated soils are located in the central part of the city (Fig. 4). The most contaminated samples are 32, 21, and 22 with 383.62, 218.30, and 176.40 mg/kg, respectively. Sample 32 was taken 100 m to the west of the industrial zone and 300 m to the south of the N5 road, from the channel of a watercourse tributary of the wadi Boussalem. This tributary collects the surface drainage water from the industrial units on both sides and from the old urban district upstream to the north, which explain the increased cumulated concentration of Pb. Samples 21 and 22 were taken from the oldest district of the city which is the most exposed to intense traffic; soil there is expected to cumulate significant content of Pb regarding its long-term exposition to pollution sources (mainly vehicles). In fact, the old downtown was urbanized earlier than the new marginal districts and it is supposed to be more exposed to previous and actual anthropogenic pollution and it still a zone of sustained intense convergent traffic (Table 4).

Commonly, the increase in lead concentrations is acknowledged for areas with heavy traffic especially in countries using leaded fuel. Since the lead is non-degradable, its level cumulates in urban soils through years and remains high (Imperato et al., 2003; Ordonez et al., 2003). Unfortunately, leaded gasoline is still widely used in developing countries. For example, in Algeria, leaded gasoline makes about 89% of local consumption. The fact that the concentrations of lead in the roadside soils are significantly increased compared to that in agricultural soils farther ward shows that the road traffic is the most likely source of lead in roadside soils in Algeria.

The total content of heavy metals in soils indicates the degree of contamination but does not indicate their mobility and toxicity. The availability of these trace elements is conditioned by their chemical mobility, anthropogenic activity, and soil physicochemical characteristics (Jing et al., 2018; Sebei et al., 2020). Soil pH is a main factor influencing heavy mobility and toxicity (Król et al., 2020; Van der Sloot & Kosson, 2010). The latter authors showed that the leachability of many heavy metals including Cd, Cu, Zn, and Pb decreases notably with alkaline pH near 8. In addition, clays exhibit strong affinity with metals and can immobilize them by adsorption (Andersson, 1979). The pH average value of Setif soil samples is 8.09 (Table 1) and the most dominant minerals within Setif soils are clays. These conditions are in favor of heavy metal immobilization which can decrease their availability and reduce the pollution they engender.

Pollution evaluation

Table 5 summarizes the descriptive statistics of chemical analysis and pollution indices of analyzed

Table 4 Geoaccumulation index (I_{geo}), pollution index (PI), and integrated pollution index (IPI) computed for Cr, Cu, Zn, and Pb within 36 geolocated soil samples from Setif city, Algeria

Sample number	Index of geoaccumulation (I_{geo})				Pollution index (PI)				Integrated pollution index (IPI)
	Cr	Cu	Zn	Pb	Cr	Cu	Zn	Pb	
01	−1.66	−0.38	−0.93	0.16	0.48	1.15	0.79	1.68	0.18
02	−0.40	0.60	1.60	1.19	1.13	2.27	4.56	3.42	10.00
03	−2.24	−0.19	−0.50	0.05	0.32	1.31	1.06	1.55	0.17
04	−0.35	0.89	1.32	1.38	1.18	2.78	3.75	3.91	12.02
05	−1.39	0.35	1.49	0.51	0.57	1.91	4.23	2.14	2.46
06	−0.91	0.28	1.12	1.64	0.80	1.83	3.26	4.69	5.60
07	−3.08	−0.33	0.34	−0.34	0.18	1.19	1.90	1.18	0.12
08	−0.10	0.30	0.97	0.41	1.40	1.84	2.95	1.99	3.78
09	−1.02	0.15	−0.22	−0.31	0.74	1.66	1.29	1.21	0.48
10	−0.62	0.60	0.94	0.78	0.98	2.28	2.89	2.57	4.15
11	−1.62	0.24	0.16	−0.23	0.49	1.77	1.67	1.28	0.46
12	0.13	0.73	1.35	0.39	1.64	2.49	3.82	1.97	7.68
13	−1.10	0.22	1.37	−0.69	0.70	1.75	3.88	0.93	1.11
14	−0.03	0.17	1.67	0.49	1.47	1.69	4.78	2.10	6.23
15	−1.74	0.66	1.31	1.02	0.45	2.38	3.73	3.04	3.04
16	−0.61	0.44	1.23	0.25	0.98	2.03	3.52	1.79	3.13
17	−0.74	0.62	1.20	−0.23	0.90	2.31	3.44	1.28	2.29
18	−0.99	0.50	1.27	0.29	0.75	2.12	3.61	1.83	2.63
19	−1.28	0.39	1.42	−0.53	0.62	1.96	4.03	1.04	1.27
20	−0.72	0.64	1.77	2.18	0.91	2.34	5.13	6.78	18.52
21	−1.15	1.19	2.08	2.48	0.68	3.42	6.33	8.40	30.91
22	−0.95	0.57	1.44	0.24	0.78	2.23	4.08	1.77	3.14
23	−1.63	0.11	0.84	0.78	0.49	1.62	2.69	2.57	1.37
24	−1.36	0.20	1.16	1.55	0.58	1.72	3.34	4.40	3.67
25	−1.32	0.01	0.17	−0.33	0.60	1.52	1.69	1.20	0.46
26	−1.16	0.37	1.04	−0.02	0.67	1.94	3.08	1.48	1.48
27	−1.34	0.59	1.73	1.04	0.59	2.25	4.98	3.09	5.11
28	−2.55	0.39	0.94	0.44	0.26	1.97	2.88	2.03	0.75
29	−1.99	0.45	0.77	0.59	0.38	2.05	2.56	2.25	1.12
30	−0.91	1.16	1.89	2.13	0.80	3.34	5.57	6.56	24.41
31	−1.57	0.02	1.01	1.45	0.51	1.52	3.03	4.10	2.41
32	−2.30	−0.01	1.96	3.30	0.31	1.49	5.86	14.75	9.98
33	−1.32	−0.02	0.38	−0.43	0.60	1.48	1.95	1.11	0.48
34	−1.13	−0.33	0.23	0.88	0.69	1.19	1.76	2.76	1.00
35	−1.22	−0.10	0.99	−0.42	0.65	1.40	2.98	1.12	0.76
36	−2.12	−0.02	0.56	1.55	0.35	1.48	2.21	4.39	1.26

soil samples from Setif city. To display the data sets of I_{geo}, PI, and IPI pollution indices (Table 2) for descriptive statistics and spatial interpretation, box plots and iso-contour maps are established (Figs. 5 and 6). Box plots are graphical representations of data using the following five values: the minimum value, the first quartile, the median, the third quartile, and the maximum value (Benjamini, 1988; Tukey, 1977).

These graphs are used to display visually the degree of dispersion and skewness in the data, how far the extreme values are from most of the data, and the abnormal data outside the boxes (outliers) plotted as individual points (see inset in Fig. 5b).

In Fig. 5a, the Cr box fall under the abscissa 0 except the unique positive value of 0.13. According to the classification of Müller (1979), the urban and

Table 5 Descriptive statistics summary of chemical analysis and pollution indices of 36 geolocated soil samples from Setif city, Algeria

Element	Sample number	Concentrations			Background values	I_{geo}			PI			IPI		
		Min	Average	Max		Min	Average	Max	Min	Average	Max	Min	Average	Max
Cr	36	10.85	43.35	99.98	61	−3.08	−1.24	0.13	0.18	0.71	1.64	0.12	4.82	30.91
Cu	36	25.99	43.75	77.58	22.6	−0.38	0.32	1.19	1.15	1.94	3.42			
Zn	36	78.95	331.20	632.50	100	−0.93	1	2.08	0.79	3.31	6.33			
Pb	36	24.09	78.26	383.62	26	−0.70	0.66	3.30	0.93	3.01	14.75			

peri-urban soils of Setif city are unpolluted (I_{geo} < l). Both Cu and Zn I_{geo} range from −0.93 to about 2 which mean that the samples are very low polluted. Pb I_{geo} plot shows relatively wide dispersion (Fig. 5a) from −0.69 to 3.3 with an extreme value recorded for sample 32 near the industrial zone. About 50% of samples exhibit Pb I_{geo} < l.33 which attributes the studied soils to very low and low polluted soils class ($1 < I_{geo} < 3$).

The box plots of PI (Fig. 5b) show that Cr displays the smallest degree of dispersion alongside Setif city with two outliers' values of 1.47 and 1.64 recorded for samples 14 and 12, respectively. The upper quartile is < 1 which mean that more than 75% of samples exhibit low $PI \leq 1$ (Faiz et al., 2009). It appears that the input of Cr in Setif soils is slightly influenced by anthropogenic activities. The outliers' values derive

as we noticed above from animal feces and organic fertilizers acknowledged as sources of Cr for soils (INERIS, 2014). The largest value of Cu PI is 3.34 and the upper quartile is < 1 (Fig. 5b) which mean that the majority of samples belong to the middle-polluted class with $1 < PI \leq 3$ (Faiz et al., 2009). The PI plots of Zn and Pb exhibit more dispersion of data with extreme values recorded within samples 21 and 32 taken from the oldest district and from the entry of the industrial zone, respectively. This argues for the evident anthropogenic input of these elements. The lower and upper quartiles of these elements range between 0.93 and 4.07 indicating that more than 50% of samples fall in the middle to high polluted soils (Faiz et al., 2009).

Based on the classification provided above, only the lower quartile is considered low contaminated
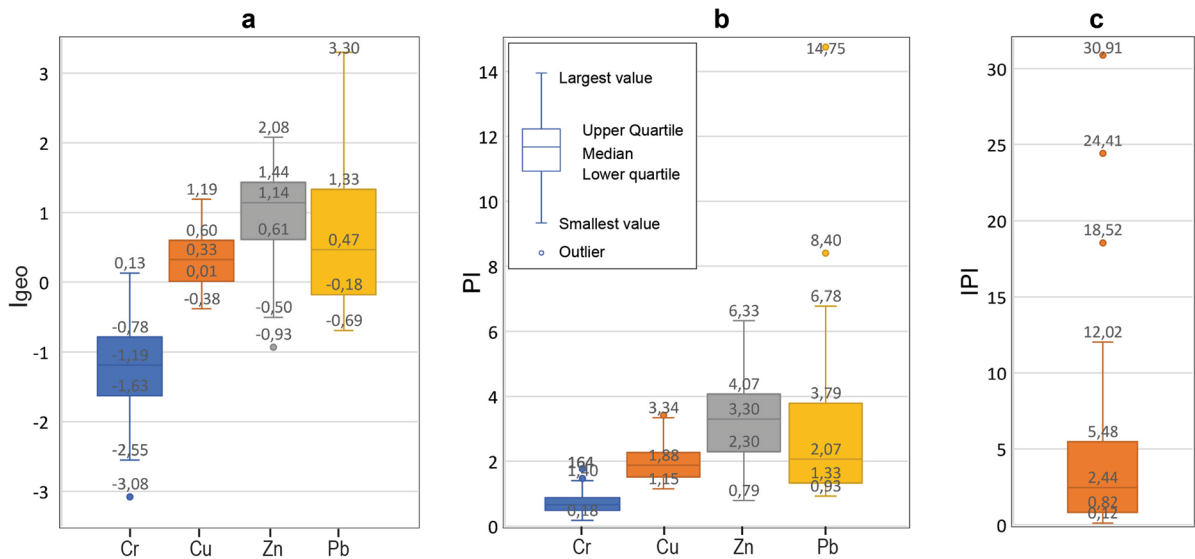
Fig. 5 Box plots of the pollution indices (I_{geo}, PI, and IPI) of urban and peri-urban soils of Setif city established for Cr, Cu, Zn, and Pb. The inset in **b** shows the explanation of boxes
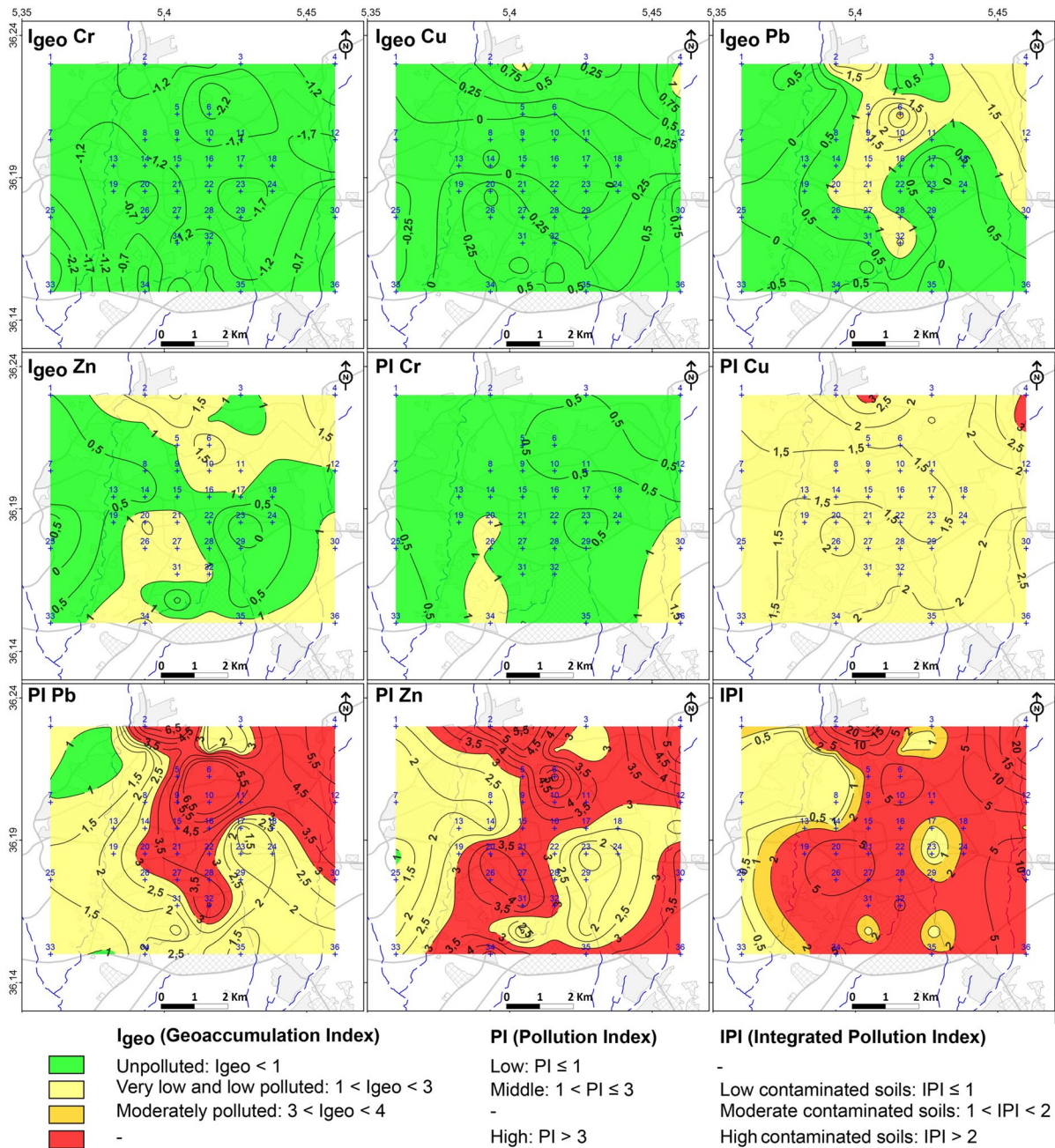
Fig. 6 Maps of the spatial variation of pollution indices (I_{geo}, *PI*, and *IPI*) of urban and peri-urban soils of Setif city established for Cr, Cu, Zn, and Pb

($IPI \leq 1$) (Fig. 5c). Moderate contaminated soils ($1 < IPI < 2$) are included between the lower quartile and the median (<25% of samples). High contaminated soils ($IPI > 2$) ranges somewhat before the median to the largest value which mean they exceed 50%.

Three highly contaminated outliers were recorded in ascending order for samples 20, 30, and 21 (Fig. 5c, Table 2) and are correlated to local domestic waste.

The lowest I_{geo} and *PI* indices were recorded for Cr. Cu indices are relatively increased and the studied

soil samples are evaluated as very low to moderately polluted with Cu. I_{geo} of Zn and Pb indicate very low to low polluted soils and *PI* indicate moderately to high polluted soils. The lowest indices were recorded within samples taken from peri-urban area away from intense agricultural activities and animal habitats and breeding. However, these indices increase near the highly urbanized districts and industrial zones in which solid wastes and atmospheric emissions of heavy metals from manufacturing plants can provide significant continuous load of heavy metals that can cumulate throw time. When considering the *IPI* indices, more than 50% of samples are evaluated as highly contaminated soils. This is an alarming environmental situation that requires instauration of rigorous policies of remediation and prevention.

The iso-contour maps of Fig. 6 display the data sets of I_{geo}, *PI*, and *IPI* pollution indices computed for urban and peri-urban soils of Setif city using four-color scale fill. Areas with non-hazardous indices are in green, high contaminated/polluted areas are filled in red, and yellow and orange colors are used for low to moderate contaminated soils (Fig. 6). Based on that, the quick visual analysis of these maps points out that (i) the I_{geo} maps are mainly filled in green (and yellow for Pb and Zn) which means that the degree of contamination with Cr, Cu, Pb, and Zn is non-hazardous (unpolluted (Cr and Cu) to very low polluted (Pb and Zn) soils); (ii) the *PI* maps are mainly filled in green for Cr, in yellow for Cu, and in yellow and red for Pb and Zn which mean that Pb and Zn represent the highest threats among the studied pollutants; and (iii) the *IPI* map is mainly filled in red with small yellow and orange areas (especially at the western side of the city adjacent to wadi Boussalem valley) which means that the soils of Setif city are highly contaminated after cumulating significant concentrations of heavy metals deriving from anthropogenic sources. The low to moderate contaminated areas seem matching with the terrains drained by wadi Boussalem in the western side of the city and by the tributaries of wadi Bouaroua near the industrial zone.

Conclusions

The chemical analysis done for thirty-six urban and peri-urban soil samples from Setif city showed that the Cd, Cr, and Cu heavy metals are non-hazardous

at Setif city scale. The Cd concentrations were found much lower than the 2 mg/kg AFNOR U44-041 admissible limit and those of Cr and Cu are under the regulatory limits of 150 mg/kg. However, Zn and Pb concentrations were found two to three times higher than the background values and are considered alarming environmental issues. The spatial distribution of these two elements shows wide polluted areas located respectively in the oldest district of the city, near the industrial zone and near uncontrolled landfill of domestic and industrial waste which correlates evidently Zn and Pb accumulation in Setif city to anthropogenic activities. In fact, these pollutants can originate from traffic, vehicle emission, particles from brakes and tires, and local industrial zone. In contrast, the spatial distribution of Cr is uncorrelatable with anthropogenic sources since the values detected near the industrial zone and the oldest district are low, whereas the highest concentrations were detected near forests, cultivated soils, and zoo. Hence, Cr derives seemly from animal feces and organic fertilizers.

Based on the I_{geo}, Cr, Cu, Pb, and Zn are mainly non-hazardous in Setif city. The *PI* indicates that Pb and Zn represent the highest threats among the studied pollutants. However, the *IPI* shows that the soils of Setif city are mainly highly contaminated after cumulating significant concentrations of heavy metals deriving from anthropogenic sources. The low to moderate contaminated areas seem matching with the peri-urban terrains drained by wadi Boussalem in the western side of the city and by the tributaries of wadi Bouaroua near the industrial zone. In fact, the heavy metal pollution of Setif city soils can be mitigated by its alkaline pH (8.09) and clayey minerals both contributing to heavy metal immobilization which can decrease their availability. The studied pollutants seem to be leached from the drained zones that exhibit relatively low to moderate integrated pollution index. Consequently, they can transfer with percolated water to contaminate groundwater downward or outside the city with surface drainage to the wadi El Melah southward to disperse outside the study area.

The cumulated amounts of heavy metals in the soils of Setif city reached alarming levels that threaten the ecosystem and the human health. In addition, heavy metals deposited on surface and not yet fixed to soils together with dust particle-bound

heavy metals suspended in the atmosphere and originated from vehicle and industrial emissions and from brakes and tires are considered dangerous direct sources of contamination to which human is exposed either by inhalation or incidental ingestion. Taking into account the expected industrial and urban development of Setif city, the heavy metal pollution will be rising prior issue. The local authorities must apply corrective measures to the current environmental situation and anticipate a future sustainable development for the city to guarantee optimal environmental conditions.

Author contribution All authors discussed the results and contributed to the final manuscript. S. Sellami carried out the soil sampling and the chemical analysis. He interpreted the data and drafted the manuscript with support of F. Dhahri. O. Zeghouan helped in conceiving the original idea of the work and the discussion of the final version. F. Dhahri established the maps and the artworks, discussed the geological and environmental issues, and helped in the interpretation of data. He also proofread the final version of the manuscript. L. Mechi and Y. Moussaoui helped in analytical procedures and interpretation of chemical data. B. Kebabi supervised the work and helped in its discussion.

Availability of data and materials All data generated or analyzed during this study are included in the tables within this manuscript.

Declarations

Ethics approval and consent to participate Not applicable.

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