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Ecological indicators and bioindicator plant species for biomonitoring industrial pollution: Eco-based environmental assessment

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ABSTRACT

Industrial pollution remains a driving force to ecosystem alteration. Pollutants are released in the atmosphere interacting in turn with other components of earth system such as plant species. Despite the long-term exposition of vegetation cover to pollution is drastically devastating, less is known about the contribution of ecological indicators for its monitoring. The aims of this study are (*i*) to introduce the ecological indicators in assessing the cement dust impact on plant species and its biomonitoring and (*ii*) to screen new indicator species for phytoremediation studies. Floristic surveys were conducted in the cement plant closeness following quadrat method. Vegetation indicators such as total plant cover, perennial and annual species densities and diversity were assessed. Bioindicator species were identified using the bioaccumulation factor (BF) and translocation factor (TF). A decrease of perennial species richness and a decline of total vegetation cover by 7 times as well as a diversity decrease ranging from 2.99 to 2.31 were found pertinent indicators of land degradation in the industrial area. Annual species densities were significantly affected by cement pollution. Species like *Lygeum spartum, Atractylis serratuloides* and *Gymnocarpos decander* arise as indicators of heavy metals pollution. Pollution in the cement plant vicinity excluded sensitive species like *Helianthemum kahiricum*, *Stipa tenassissima*, *Plantago coronopus*. This study allowed the identification of indicator species of potential use in phytoremediation applications and emphasized the possibility of relaying on the vegetation indicators to assess the impact of cement pollution.

1. Introduction

The industrial technologies may have many undesirable consequences on the environmental state due to gaseous emissions and untreated wastewater including hazardous compounds. Consequently, air pollution and soil contamination have become a major threat to plant survival in the industrial vicinity and have been identified as possible cause of land degradation (Liu et al., 2017, Paoli et al., 2015).

Cement plant has been recognized as one of the most pollutant industrial factories. Cement dust implies negative impact on the environmental balance, and generates polluting gases (Gallo et al., 2014) harming diverse vegetation types (Iqbal and Shafiq, 2000, Li et al., 2015). In urban areas, the establishment of cement plant leads to several damages affecting air quality as well as soil–plant interface (Bermudez et al., 2010, Nicholsonet al., 2003). A main concern stem from soil contamination due to cement factories emissions. Indeed, a wide range of pollutants were then produced, mainly reported by gaseous emissions such as NO_2, SO_2 and CO_2. Furthermore, heavy metals and metalloids (Hg, Cd, Zu, Cu, Fe and As) and particulate matter of 10 μm size or less were identified as byproducts of cement manufacturing (Al-Khashman and Shawabkeh, 2006; Hua et al., 2016; Paoli et al., 2014). Pollutants emitted by industrial sources are discharged into the atmosphere and are then settled on soil ecosystem, including vegetation cover. Consequently, contaminated soil interacts with different ecological processes,

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biogeochemical cycles, water regulation and filtration, and other deposited pollutants that would leach in the substrates. As a result, the function of contaminated ecosystem is gradually disturbed, entailing an imbalance of the natural soil-vegetation interactions (Belon et al., 2012).

Similarly, the vegetation cover constitutes a basic component of the ecosystem providing multiple services to the livelihood community. Vegetation cover stands out as a proper indicator assigning a wide integrative data informing about the spatial variation of the surrounding conditions. The variation of the structure and plant communities contribute also in informing about the environmental factors and their associated impacts (Wei et al., 2018). In drylands, vegetation cover is submitted to different stresses related to low rainfall, drought and water availability, it plays, thus, an important key role in many environmental processes gathering several protection mechanisms (Omuto et al., 2010). Most of North African species have very scarce data and even the information provided by local and regional flora sets lack of precision (Jauffret and Visser, 2003). Many studies listed the impact of the cement plant pollution on the soil and the air components (Jena et al., 2020, Li et al., 2020, Schuhmacher et al., 2017, Hua et al., 2016, Wang, 2014). However, the investigation of its effects on the vegetation cover driving to areas degradation is scarce and limited to few studies where the physiological response of some vegetal species growing in cement plant vicinity was investigated (Salama et al., 2011, Junior et al., 2009). The negative effect of the cement dust on the plant growth, lipid and ionic tissues composition have been largely demonstrated, However, Drack and Vázquez (2018) depicted a positive effect of the cactus growth. Despite the numerous studies of plant physiological traits, none of them has focused on the pollution impact at the ecological scale and on the use of ecological indicators for screening vegetation cover. Individual species, plant communities and at a larger scale, ecosystem can be impacted by pollution drivers. Notably, the related macroecological attributes have been widely used in aquatic ecosystem for species distribution assessment in polluted environment (Burgos et al, 2020, Vanmensel et al, 2020, Orlando et al, 2020). Yet, their involving for assessing terrestrial vegetation has been lacking. Spatial dissimilarities in terms of individual species and communities may serve for both assessing pollution impact and diagnosing potential indicators species. This unprecedented work stands out with a concise ecological understanding, driving to a better land resources management. Ecological attributes related to the vegetation cover structure, such as perennial species density, annual species density, species diversity and vegetation cover are important indicators to footprint environmental disturbances specifically industrial pollution (Belgacem et al., 2011). These attributes may describe the vegetation state and allow a better understanding of floristic composition, evidencing the emergence of both sensitive and tolerant species under pollutant impact and responding to various environmental factors (Fakhry and Migahid, 2011; Jauffret and Lavorel, 2003). Setting these attributes for pollution indication is still lacking. This study aimed to *(i)* implement ecological indicators to assess the cement plant emissions impact on the spontaneous vegetation surrounding industrial area and *(ii)* screen new plant indicators of pollution for phytoremediation application.

2. Material and methods

2.1. Study area description

The study area is located around Gabes cement plant, Tunisia between 33° 51′ 57.61″ N and 9° 59′ 38.85″ E covering 4 sites S1, S2, S3 and SC (Fig. 1). Established in 1977, the plant location was based on the availability of raw materials (limestone, marly limestone and clay), the significant infrastructure establishment (port, plants, pipelines, industrial complex) and the strategic central position in the South (Haydar,

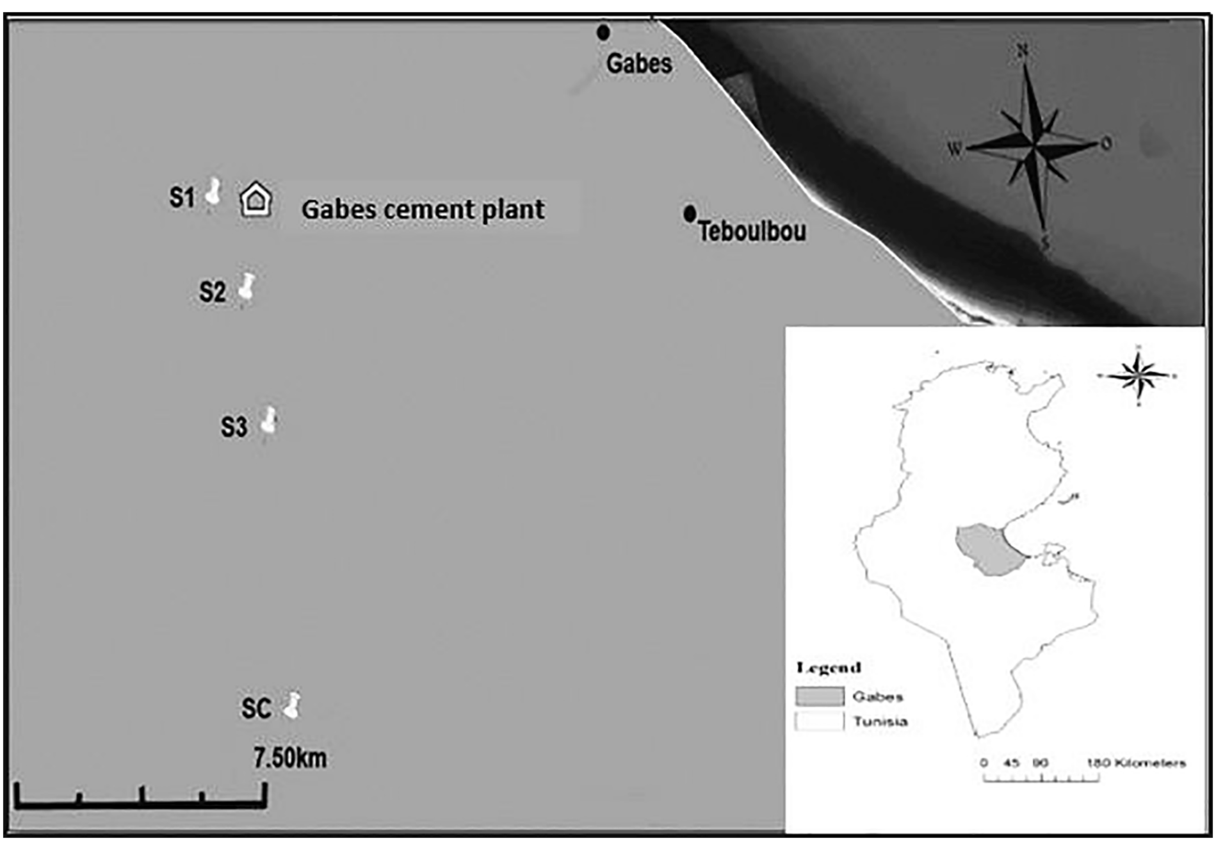

Fig. 1. Gabes governorate, Tunisia map; The studied areas locations (Gabès, Tunisia); the first site (S1) at 250 m from the cement plant location, the second site (S2) at 3 km, the third (S3) at 6 km and the control (Sc), non-polluted zone, at 12 km.

1986). This factory is located at 10 km Northwestern the center of Gabes city, Tunisia. This region covers an area of 7.166 km^2. It is localized in the Mediterranean rives (Fig. 1) and is characterized by the presence of coastal oases. The climate is characterized by dry air, scarcity and irregular rainfall that oscillate between 88 and 230 mm/year, large daily and annual temperature fluctuations with 18.4 °C annual temperature mean and a long hot summer (www.meteo.tn).

2.2. Sites localization

Four sites were selected for the soil and vegetation study, according to their distance to the cement plant and to the similarities of the slope, soil nature, depth, and pH as well as the size of the area. All the investigated sites were not submitted to land use, isolated from any disturbance factor such as grazing, roads or other interferent pollutant source. All sites are characterized by sandy clayey soils. The first site is situated in the close vicinity of the cement plant, located at 250 m (S1), the second site is at 3 km (S2), the third is at 6 km (S3) and the control, non-polluted zone, is located at 12 km (Sc). The distance between the cement plant and the diverse study sites was selected according to the wind direction and the estimated cement dust propagation.

2.3. Soil chemical characterization

The total carbonates $CaCO_{3T}$ content was determined according to the NF ISO10693 LANO methods, the active carbonate $CaCO_{3A}$was measured by the ISO X31-106 method. The organic matter content was determined by Anne methods X31-109. A random collection of soil was carried out for determining the concentration of heavy metals in the site. A composite soil sample served for heavy metals analysis by collecting 36 subsamples dispersed randomly in the site at the depth of 5–20 cm. For determining heavy metals content in plants twelve soil samples were collected in the root zone of each collected plant species. Chromium (Cr), Cobalt (Co), Zinc (Zn) and plomb (Pb) contents were determined by acid digestion. 1 g of soil sample were dried at 90 °C until constant weight and digested in acidic mixture of 3 mL HNO_3, 100 μL HF, 3 mL of H_2O_2 and 3 mL distilled water and the digested samples were diluted to 25 mL. Heavy metals in samples were quantified using Atomic Absorption spectrometry AAS (*PerkinElmer,* Analyst 800).

2.4. Ecological indicators

2.4.1. Field surveys

Vegetation surveys were conducted following quadrats point method (Daget and Godron, 1995). The sampling units were reduced into points. These points are spaced regularly along lines. Twelve lines of 20 m length each were installed at each site. Each three lines were placed according to the axis × y z in the northern, southern, eastern and western directions. At each line a metal rod was picked, by stitching tapered edge perpendicularly to the ground each 20 cm along the line (Boudet, 1977). For each picked point, the contact of a species either by its leaves, rod or by its inflorescences allows the indication of the species in the flora list.

2.4.2. Macroecological indicators

The vegetation cover (Rv) was measured. This parameter is proportional to the surface covered by the vertical projection of the aerial parts of the plant species. The Rv ratio was expressed as a percentage of the number of points where the species are present and the total number of sampling points expressed by the formula

$$RV = (n/N) \times 100 \quad (1)$$

where n is the number of hits in all plant species and N is the total number of hits multiplied by 100 (Belgacem et al., 2011). The relative abundance (RA) was assessed. This parameter reflects the specific recovery and is expressed as the ratio between the points number where the existing species and the total number of read points, multiplied by 100. It is expressed by the formula:

$$RA = (ni/N) \times 100 \quad (2)$$

where n*i* is the number of hits of species *i* (Belgacem et al., 2011). It should be noted that the linear analysis allowed the identification of key species and their respective frequencies. Note that the employed approach to count the individuals belonging to different plant species, along at each measured line (2 m^2 for annual and 20 m^2 for perennial), while assessing the density.

The diversity of plant species was estimated by evaluating alpha diversity. The latter is assessed by the Shannon and Wiener Index H' and the evenness R. The Shannon and Wiener index (H') is expressed as

$$H' = -\Sigma fi \log 2fi \quad (3)$$

where fi = ni/N is the relative frequency of the *i*-the species. Note that, for a given number of species, H' increases as the diverse species have comparable recoveries rates (i.e., comparable relative frequencies fi), while H' decreases in the case that some of the species have strong recoveries (i.e., high values of *fi* just for some species) and tend to dominate the control. Note that, H' in (3) is the entropy of the species (discrete) probability distribution: the higher is H' at a given site, the harder is to guess the specific species that is possible to encounter at that site (higher degree of uncertainty). In other words, for a given number of species, the higher (lower) is H' the more (less) heterogeneous is the composition of the vegetation/flora at a given site.

As an additional indicator about the structuring of the vegetation at a given site, it is relevant to quantify the degree of *uniformity* among the set of species detected at a given site. (Spellerberg, 2005). In this regard, the evenness index is evaluated as

$$R = H'/H_{max} \quad (4)$$

where H_{max} is the counterpart of the Shannon and Wiener Index assuming an equal relative frequency for all the recorded species at a given site (i.e., it represents the condition of maximum degree of uniformity in terms of species presence). Note that, the evenness ranges from 0, i.e., one single species dominates the site vegetation, to 1, i.e., the species detected at a site are equally present (or equally probable).

Furthermore, it is possible to evaluate the beta diversity using Jaccard index which evaluates the inter-diversity and similarities between sites in terms of floristic composition. This index was determined based on an exhaustive flora list including all the species found along the measurement lines, as well as those found during the density measurement (all perennial present in 20 m^2 and all existing annual plants in 2 m^2 for each read line). It results in the floristic similarity Jaccard index, calculated using the following formula:

$$[Pj\ (\text{recorded x and y}) = c/(a + b - c)] \quad (5)$$

where Pj = the index of similarity; a = the number of species found in the statement x; b = the number of species found in the statement y; c = the number of species common to both x and y readings (Van Dyke, 2008).

2.4.3. Principal component Analysis, model regression and sensitivity analysis

In this section, the impact of environmental heterogeneity on the ecological indicators have been investigated. The adopted approach aims to quantify the possible influence of the recorded soil properties (see Sec. 2.3) on the evaluated ecological indicators (see Sec. 2.4.2), as well as extracting the most influential soil properties.

For each variable (i.e., either a soil property or an ecological indicator), the corresponding sample population is made of 48 observations in total, with 12 observations per each one of the 4 sites considered in this study. Inspection of the sample population of each variable (see Sec. 3.4) reveals that the corresponding variability is majorly ascribed to the difference across the four sites (i.e., intra-site variability), rather than the possible internal variations within a given site (i.e., inter-site variability). In other words, the major source of variability for each variable descend to the heterogeneity across the diverse sites, rather than the within site heterogeneity. This has leaded to focus on the search of possible influences of the soil properties onto the ecological indicators, considering the observations pertaining to all the sites jointly (rather than conduct site-specific analysis).

A preliminary investigation (see Sec. 3.4) points out a strong degree of correlation between the diverse soil properties. Thus, a Principal Component Analysis (Wold et al., 1987) was performed in order to identify the independent Principal Components (PCs), which can be perceived as *composite* soil properties (i.e., the PCs of the soil properties). For the same reason, the PCs for the ensemble of the ecological indicators have been evaluated, identifying a novel set of independent *composite* ecological indicators.

Therefore, the identification and quantification of possible relationships between the most relevant *composite* soil properties and the major *composite* ecological indicators has been put forward. Specifically, simple interpretative models have been identified allowing to (partially) capture (when possible) the ongoing influence of the soil properties PCs onto the ecological indicators' PCs. By leveraging on such model(s), the quantitative assessment of the sensitivity of the identified *composite* ecological indicators was provided with respect to the most relevant *composite* soil properties.'

The results of the procedure described in Sec. 2.4.3. are reported in Sec. 3.4

2.5. Bio-indicators species identification

Plant shoots and roots were excavated entirely within a depth of 15 cm and kept with the soil beneath each sampled plant. The concentration of Cr, Co, Zinc and Pb were determined by digesting grounded plant material in concentrated acid mixture described in the section 2.3. Abundant species identified from the floristic surveys were selected for testing their potential of bioaccumulation (MBF) expressed as the ratio between heavy metals concentration in the root and soil and translocation of heavy metals (MTF) expressed as the ratio between heavy metals concentration in the shoot and the soil (Malik et al, 2010). According to the results bioindicators are identified.

2.6. Statistical analysis

The variance analysis (ANOVA) was used for a classification criterion using SPPS.22. It compares the average of the groups formed by one or more classification criteria to be analyzed. This analysis gives information about the occurrence of significant variability between the sites and parameters calculated based on the distance. The critical threshold of a difference observed between the averages is coded as non-significant (NS) for $p > 0.05$. A multiple variance comparison of the four sites was conducted using Kruskal and Wallis test (Addinsoft, 2016).

3. Results

3.1. Soil properties

Soil surrounding the industrial area appeared with an alkaline pH, However, distant sites showed less alkalinity (Table 1). Total calcium carbonates $CaCO_{3T}$ and active calcium carbonates $CaCO_{3A}$ exhibited a keen variation between SC and the close site to the cement plant S1 and S2 where the content was significantly higher. This would be explained by the limestone enrichment due to the calcareous soil and the released $CaCO_3$ during Portland cement production process. Similarly, the contamination of the close site was significantly marked by high contents of Cr, Co, Zn and Pb compared to theirs in further sites (S2, S3 and SC).

Table 1
Soil properties in the sites; site 1 (S1), site 2 (S2), site 3 (S3) and control site (SC).

	S1	S2	S3	SC
pH	8.62 ± 0.07^a	8.10 ± 0.09^b	8.12 ± 0.06^b	7.34 ± 0.08^c
EC (μs cm^{-1})	648.37 ± 5.06^b	680.2 ± 11.54^a	372.56 ± 10.16^c	212.56 ± 3.30^d
OM (%)	12.98 ± 3.45^c	24.05 ± 1.91^b	33.97 ± 0.95^a	39.20 ± 1.03^a
$CaCO_3$ t (%)	34.07 ± 0.03^a	18.57 ± 0.99^b	10.49 ± 0.04^c	8.80 ± 0.06^d
CaCO3a (%)	29.91 ± 1.52^a	20.03 ± 1.99^b	14.90 ± 1.18^c	4.48 ± 0.48^d
Cr (ppm)	18.92 ± 0.10^a	2.77 ± 0.11^b	1.31 ± 0.14^d	1.72 ± 0.02^c
Co (ppm)	2.20 ± 0.03^a	0.20 ± 0.05^c	0.47 ± 0.06^b	0.23 ± 0.02^c
Zn(ppm)	14.96 ± 0.03^a	7.47 ± 0.06^b	6.76 ± 0.04^c	3.42 ± 0.04^d
Pb (ppm)	83.86 ± 0.97^a	11.82 ± 0.07^b	5.17 ± 0.03^c	3.14 ± 0.04^d

*EC: Electrical Conductivity, OM: Organic Matter, $CaCO_{3T}$: Total carbonates, $CaCO_3$: Active carbonates.Data represent mean values ± SD

3.2. Community traits

3.2.1. Vegetation cover

The vegetation cover (Fig. 2a) was lower 7 times in the cement plant vicinity (site 1), compared to distant sites (2, 3 and the control). A significant variation of the vegetation cover between the four sites ($p = 0.03$) was noticed. Multiple comparisons exhibited a significant variation between the first site and the control site ($p = 0.003$), the variation

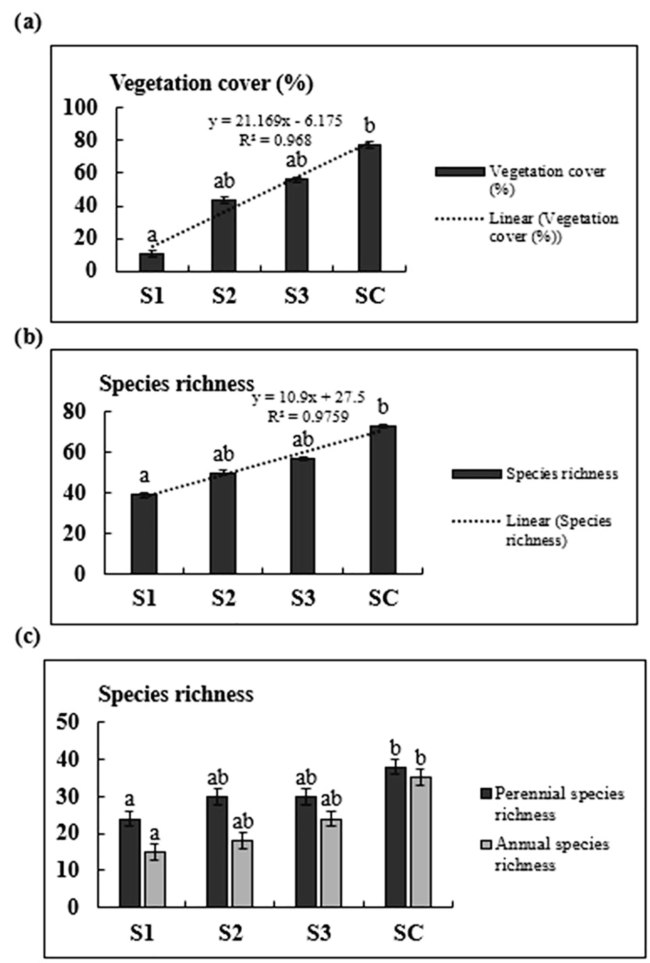

Fig. 2. The variation of (a): The total vegetation cover, (b): The total species richness, (c): Perennial and annual species richness in the study sites ± SD, a, ab, b: groups identified by Dunn's test at 95% limits of confidence.

was also significant between the first site and the third site as well as between the second and the control site ($p < 0.05$).

3.2.2. Flora richness

Floristic richness changes are shown in Fig. 2. An increase of vegetation rate was noticed. This ranges from about 11% in the first site to 77% in the control one. The number of species and the diversity measurement of the found community are presented in Fig. 2b. At a close distance from the factory (S1), the flora richness was deeply affected by cement plant pollution. It was reduced by 1.9 times compared to the non-polluted area (SC). Moreover, the variation of this parameter was highly significant between sites ($p = 0.002$).

3.2.2.1. Perennial species richness. Linear variation in the perennial species (Fig. 2c) between the investigated sites was recorded. Richness ranged from 24 species in the nearest site to the plant (S1), to 38 species in the control site (SC). The variance analysis showed a significant variation in the perennial species richness between the sites ($p < 0.05$). Kruskal and Wallis test displayed a significant variation between the S1 and the control site ($p < 0.05$). At this site (S1), the abundant perennial species were *Helianthemum intricatum, Lygeum spartum, Gymnocarpos decander* and *Atractylis serratuloides*, while in the second site (S2) *Gymnocarpos decander, Annarhinum brevifolium, L. spartum* and *Zygophyllum album* were present. The third site (S3) was characterized by the species of *Annarhinum brevifolium, H. intricatum, Herniaria fontanesi, Erodium glaucophyllum* and *Reaumuria vermiculata*. Finally, in the control site, the abundant species were *Artemisia herba alba, G. decander* and *L. spartum*.

3.2.2.2. Annual species richness. An increasing number of annual species (Fig. 2c) from S1 to the SC; the annual species richness varied between 15 and 35 species. The analysis of variance exhibited a significant difference between the investigated sites ($p = 0.05$). The multiple comparison showed a significant variation between the first and the control site ($p = 0.006$) as well as between the S2 and the SC ($p = 0.03$). Near to the cement plant, the main species present were *Launaea quercifolia* and *Launaea angustifolia* while in the S3 was marked by the abundance of *Stipa capensis, Asteriscus pygmaeus, Diplotaxis harra* and *Hippocrepis bicontorta*. The SC was the richest site in annual species dominated by *Schismus barbatus* and *Asteriscus pygmaeus*.

3.2.3. Species density

Perennial species density variation (Table 2) was boosted in the SC comparing to the other sites. Indeed, some species were totally absent in the S1 such as *Artemisia compestris, A. herba alba, Haloxylon scoparium* and *Astragalus armatus*. However, other species were found in the four studied sites and were *L. spartum, A. serratuloides, G.decander, E. glaucophyllum* and *H.intricatum*. In the S1 and S3, perennial species densities were low respectively 4.04 and 4.15 plant/m^2 while increased in the distant site 6.13 plant/m^2.

The annual species densities (Table 3) were higher in further sites of the cement plant (18.82 and 17.10 plant /m^2 in S3 and SC, respectively), however, lower density was found in S1 (9.3 times less than in the control site). The variance analysis showed that the variation between the sites was significant. *L. quercifolia*, was found the most dominant, followed by *L. angustifolia, Koelpimia linearis* and *S. barbatus*. The later showed a higher density when being distant from the pollution source. Similarly, *A.pygmaeus* exhibited the same behavior. The densities of *A. pygmaeus, Asteriscus graveolens, Atractylis flava, Euphorbia retusa, Ericaria pinnata, Kolerea pubescens, Fagonia glutinosa* were higher near to the cement plant while other densities were progressively decreased starting from the control zone to the cement plant such as *D. harra* or increased like *L. quercifolia* and *Plantago ovata*. These species could be considered as well acclimated in this polluted environment.

Table 2
Perennial species density (n = 12) (mean ± SD) in the sites; site 1(S1), site 2 (S2), site 3 (S3) and control site (SC).

Species	Sites 1	2	3	SC	p-value
Annarhinum brevifolium	0.00 ± 0.00^{c}	0.45 ± 0.05^{b}	0.92 ± 0.07^{a}	0.00 ± 0.00^{c}	*
Argylobum uniflorum	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.03 ± 0.02^{a}	0.00 ± 0.00^{a}	**
Aristada ciliata	0.02 ± 0.01^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	**
Artemisia compestris	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.07 ± 0.03^{a}	0.00 ± 0.00^{b}	*
Artemisia herba alba	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	2.12 ± 0.37^{a}	*
Astragalus armatus	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.07 ± 0.02^{a}	**
Atractylis serratuloides	0.43 ± 0.05^{a}	0.32 ± 0.10^{ab}	0.28 ± 0.10^{b}	0.07 ± 0.04^{c}	*
Deverra tortuosa	0.00 ± 0.00^{b}	0.38 ± 0.06^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	*
Erodium glaucophyllum	0.15 ± 0.03^{b}	0.28 ± 0.06^{ab}	0.35 ± 0.06^{a}	0.30 ± 0.16^{ab}	*
Gymnocarpos decander	0.82 ± 0.09^{a}	0.87 ± 0.08^{a}	0.05 ± 0.04^{c}	0.63 ± 0.06^{b}	*
Helianthemum kahiricum	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.45 ± 0.06^{a}	*
Helianthemum seliimit	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.13 ± 0.06^{a}	*
Haloxylon scoparium	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.12 ± 0.04^{b}	0.28 ± 0.09^{a}	*
Helianthemum ellipticum	0.00 ± 0.00^{b}	0.28 ± 0.04^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	*
Helianthemum fontanesi	0.02 ± 0.01^{c}	0.00 ± 0.00^{c}	0.48 ± 0.01^{a}	0.13 ± 0.02^{b}	*
Helianthemum intricatum	0.85 ± 0.07^{a}	0.50 ± 0.30^{a}	0.78 ± 0.21^{a}	0.32 ± 0.24^{a}	**
Helianthemum sessi	0.01 ± 0.00^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	*
Hernaria fontanesi	0.02 ± 0.01^{a}	0.00 ± 0.00^{a}	0.48 ± 0.44^{a}	0.13 ± 0.07^{a}	**
Launaea residifolia	0.65 ± 0.07^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	*
Lygeum spartum	0.92 ± 0.06^{b}	1.03 ± 0.06^{b}	0.07 ± 0.03^{c}	1.23 ± 0.02^{a}	*
Plantago albicans	0.07 ± 0.02^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	*
Reaunuria vermiculata	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.42 ± 0.06^{a}	0.00 ± 0.00^{b}	*
Stipa tenassicima	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.27 ± 0.06^{a}	*
Stipa plumosa	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.03 ± 0.02^{a}	0.00 ± 0.00^{b}	*
Thymus capitatus	0.00 ± 0.00^{b}	0.2 ± 0.14^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	*
Zygophyllum album L.	0.08 ± 0.02^{b}	0.55 ± 0.02^{a}	0.07 ± 0.06^{c}	0.00 ± 0.00^{b}	*
Total	4.04	5.18	4.15	6.13	

Data represent means of twelve measures at the limit 95% of confidence, *$p < 0.05$

3.2.4. Floristic diversity

Diversity was assessed by calculating alpha indices (Table 4). Alpha diversity indices (H' and R) varied from one site to another. The lowest value (2.31) was registered in the S1, however, the highest was found in the SC. The variance analysis showed significant variation of H' between the sites ($p = 0.02 < 0.05$). In the SC, the significant increase of diversity can be explained by the development of novel species. These species could be sensitive to pollution. Evenness exhibited an overall decrease from the cement plant area to the furthest sites.

Jaccard index of diversity is listed in table 5. The overall index showed very low common species between sites with<15% of common species. The SC exhibited floristic heterogeneity compared to sites S2 and S3 with low values of the Jaccard index. Moreover, it was noticed

Table 3
Annual species density (mean ± SD) in the sites; site 1 (S1), site 2 (S2), site 3 (S3) and control site (SC).

Species	Sites 1	2	3	SC	p-value
Asteriscus pygmaeus	0.00 ± 0.00[c]	0.00 ± 0.00[c]	2.33 ± 0.23[b]	4.33 ± 0.32[a]	*
Astragalus tenuifolius	0.00 ± 0.00[b]	1.00 ± 0.21[a]	0.83 ± 0.15[a]	0.00 ± 0.00[b]	*
Atractylis flava	0.00 ± 0.00[c]	0.00 ± 0.00[c]	2.33 ± 0.10[a]	0.67 ± 0.30[b]	*
Bromus madritensis	0.00 ± 0.00[b]	0.50 ± 0.21[a]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	*
Diplotaxis harra	0.17 ± 0.05[c]	1.17 ± 0.12[b]	3.33 ± 0.08[a]	1.50 ± 0.31[b]	*
Euphorbia retusa	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	1.50 ± 0.18[a]	*
Ericaria pinnata	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	1.83 ± 0.14[a]	*
Fagonia glutinosa	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.67 ± 0.26[a]	*
Hippocrepis bicontortalois	0.17 ± 0.10[c]	1.00 ± 0.20[b]	2.67 ± 0.30[a]	0.00 ± 0.00[c]	*
Koelpimia linearis	1.17 ± 0.41[a]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	*
Kolerea pubescens	0.00 ± 0.00[b]	0.00 ± 0.00[b]	1.50 ± 0.19[a]	0.00 ± 0.00[b]	*
Launaea angustifolia	2.33 ± 0.10[a]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	*
Launaea quercifolia	2.83 ± 0.17[b]	4.66 ± 0.38[a]	2.50 ± 0.84[b]	0.83 ± 0.16[c]	*
Lotus halophilus	0.00 ± 0.00[c]	1.33 ± 0.18[a]	1.00 ± 0.02[b]	0.00 ± 0.00[c]	*
Medicago minima	0.17 ± 0.01[a]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	*
Paronychia arabica	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.83 ± 0.10[a]	*
Plantago coronopus	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.00 ± 0.00[b]	0.50 ± 0.03[a]	*
Plantago ovata	0.33 ± 0.11[c]	0.83 ± 0.03[b]	2.33 ± 0.09[a]	0.00 ± 0.00[d]	*
Schismus barbatus	1.00 ± 0.03[b]	0.83 ± 0.04[c]	0.00 ± 0.00[d]	4.50 ± 0.04[a]	*
Total	8.17	11.32	18.82	17.10	

Data represent means of twelve repetitions measures at the limit 95% of confidence,
$p < 0.05$, the variance between sites is significant

Table 4
Change indices of α-diversity (H' and R) (±SD) in the sites S1, S2, S3 and SC.

Sites	H' (n = 12) Shannonand Wiener Index ± SD	Evenness (R) (n = 12) (equitability)±SD
1	2.31*±0.01	0.68* ± 0.04
2	2.91*±0.01	0.55* ± 0.03
3	2.49*±0.02	0.43* ± 0.02
Control	2.99*±0.05	0.46* ± 0.01

Data represent means of α-diversity index in the four sites at the limit 95% of confidence,
* = $p < 0.05$.

Table 5
Variation of Jaccard Index (β diversity) of similarity between sites.

Jaccard Index (βdiversity)(n = 12) **	Sites 1	2	3	Control
1	1			
2	0.12	1		
3	0.11	0.13	1	
Control	0.15	0.07	0.09	1

Data represent means of β-diversity index in the four sites at the limit 95% of confidence,
** = p ˃ 0.05.

that little common species were found with other sites. Hence, heterogeneity of species composition revealed between S2 and SC with<7% of common species. The low index recorded in the S3 and SC was the consequence of different species occurrence when compared to the SC. In contrast, the S1 have more common species with the other sites S2, S3 and SC.

3.3. Bio-indicators

Abundant species encountered in S1, S2, S3 and SC were analyzed for their total heavy metal uptake (Fig. 3). Maximum of Zn bioaccumulation have been recorded within *L. spartum* followed by *G. decander*. The Pb, Co and Cr translocation have been more important in *A. serratuloides, G. decander and L. quercifolia*. The highest Co translocation has been detected in *H. intricatum*.

Higher MTF and MBF were noticed in perennial against annual species. The highest MBF was recorded in *L. spartum* followed by *G. Decander* however the MTF revealed more important in *L. spartum* followed by *A. serratuloides*. This could explain their adaptation potential. For perennial species, the MBF > 1 except for *E. glaucophyllum*. However, annual species showed that MBF < 1. All tested species depicted an MTF > 1.

3.4. Soil properties and ecological indicators: Principal Components, model regression and sensitivity analysis

The results of the approach described in Sec. 2.4.3 is presented in Fig. 4. The frequency distributions of (a) the soil properties (Fig. 4a) and (b) the ecological indicators (Fig. 4b) have been firstly inspected. For both (a) and (b) the variability across the four sites (i.e., intra-site variability) tended to be larger than the variability within a given site (i.e., inter-site variability).

To formally quantify the latter aspect, the variance of each variable was evaluated (i.e., $V(\Delta)$, being Δ a given variable under analysis) by mutating the formula developed in the context of multi-models approach (Ye et al., 2004).

$$V(\Delta) = \frac{1}{4}\sum_{j=1}^{4} V[\Delta|S_j] + \frac{1}{4}\sum_{j=1}^{4} \left(E[\Delta|S_j] - E[\Delta]\right)^2 \quad (6)$$

where $V[\Delta|S_j]$ and $E[\Delta|S_j]$ are the variance and the expected value of Δ conditional to site j-th, respectively, $E[\Delta]$ is the expected value of Δ. The ¼ factor represents the probability associated to each site (i.e., equiprobability of the sites). The first r.h.s term in (1) quantifies the intra-site variability while the second r.h.s. term quantifies the inter-site variability of Δ. Table 6 lists the values of $V(\Delta)$ and the relative percentage ascribable to the intra-site and inter-site contributes: the latter revealed always significantly larger than the former for all the undertaken variables. Subsequently, this has driven to spotlight the possible influences of the soil properties onto the ecological indicators, considering the observations pertaining to all the sites jointly (rather than conduct site-specific analysis).

The linear correlation coefficient (i.e., ρ) for the set of recorded soil properties is depicted in Fig. 5. Fig. 5a depicts the ensuing values of ρ, all the diverse pairs of soil properties, revealed a not negligible level of correlation between many of the soil properties (e.g., ρ(CaCO3a, OM) = -0.9606). Fig. 5b depicts the values of ρ associated to the pairs of ecological indicators. Again, a marked level of correlation for most of the evaluated ecological indicators has been found.

The last analysed leaded to perform a PCA enabling the extraction of the most relevant *composite* soil properties (i.e., most relevant PCs of the soil properties) and the major *composite* ecological indicators (i.e., most relevant PCs composite ecological indicators). As a common preliminary step, all the variables were standardized in order to avoid the influence of discrepancies in the variations range of the diverse variables (e.g., compare the range of variations of pH and EC). Inspection of the eigenvalues associated to the first two PCs of the soil properties revealed

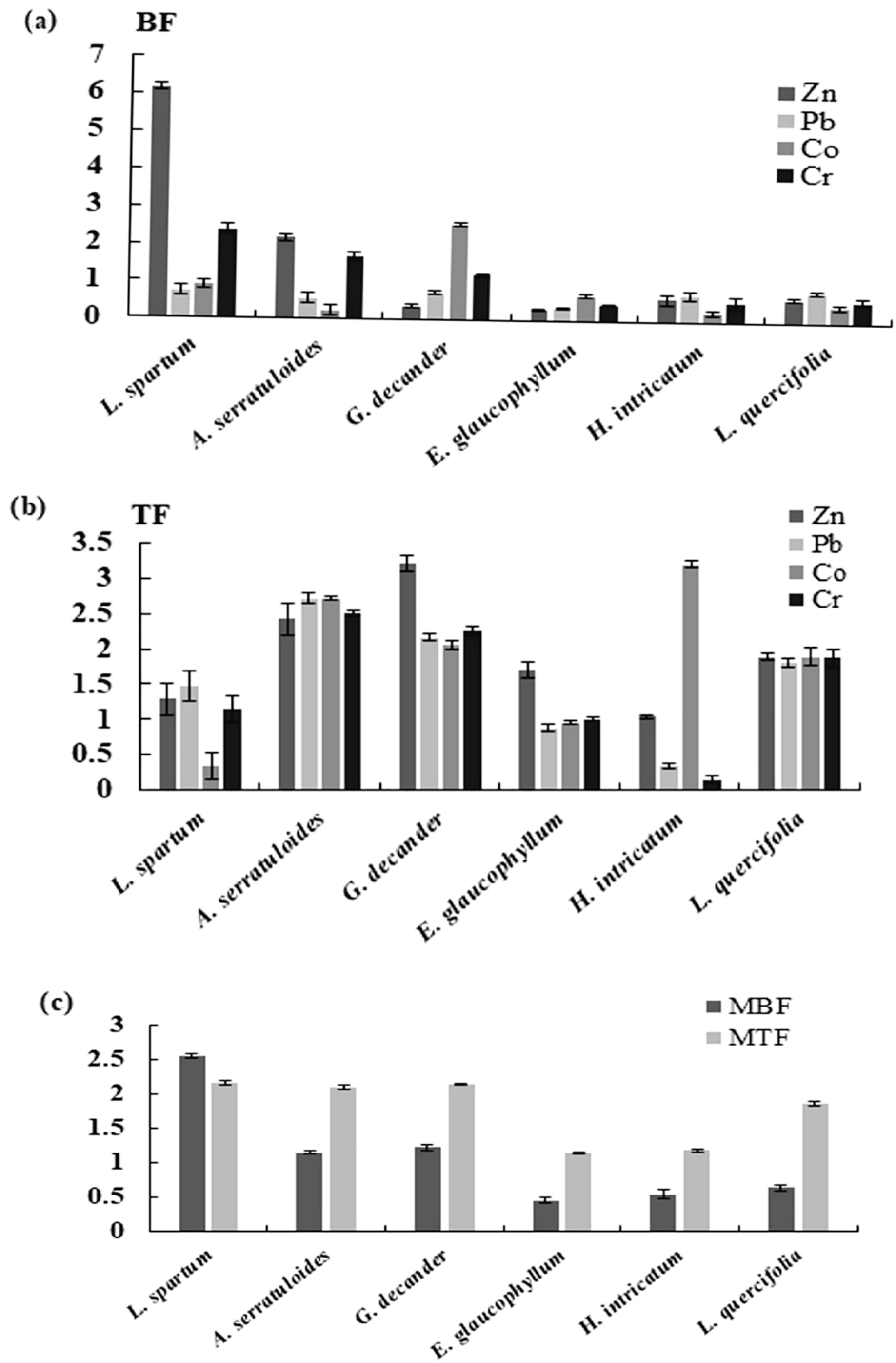

Fig. 3. Bioaccumulation factor (BF), translocation factor (TF) of Zn, Pb, Co and Cr and mean bioaccumulation factor MBF and mean translocation factor MTF of potential indicators species ± SD.

that the first (i.e., PC_1^S) and second (i.e., PC_2^S) PC explained 87% and 9.6% of the total variance in the set of observed soil properties, respectively. Thus, in the following analysis, only the first two *composite* soil properties were retained. Similarly, the results of the PCA for the ecological indicator revealed that PC_1^I and PC_2^I explained 81% and 13% of the variance in the set of evaluated ecological indicator. Thus, only PC_1^I and PC_2^I were retained in the subsequent analysis.

The table 7 lists the loading factor for (PC_1^S, PC_2^S) and (PC_1^I,PC_2^I) (Fig. 6 depicts also the loading factors of the original variables for clarity). Inspection of the loading factors for PC_1^S revealed even positive values of the loadings associated to the diverse original soil properties with exception for the negative load attributed to the organic matter (also Fig. 5a). Thus, PC_1^S can be interpreted as a measure of the 'general level of contamination of the soil'. Moreover, it is to be noted that the highest loads (in terms of absolute values) were assigned to OM, $CaCO_3$t, $CaCO_3$a and Zn which represent those soil properties that were clearly varying with some regularity (either increasing or decreasing) as a function of the distance from the cement plant (Fig. 4a). At the same time, the PC_2^S (which aims at explaining the remaining variability in the dataset of soil properties) exhibited the lowest loads for OM, $CaCO_3$t, $CaCO_3$a and Zn and the highest loads which were assigned to those variables that do not clearly vary in a regular fashion with the distance

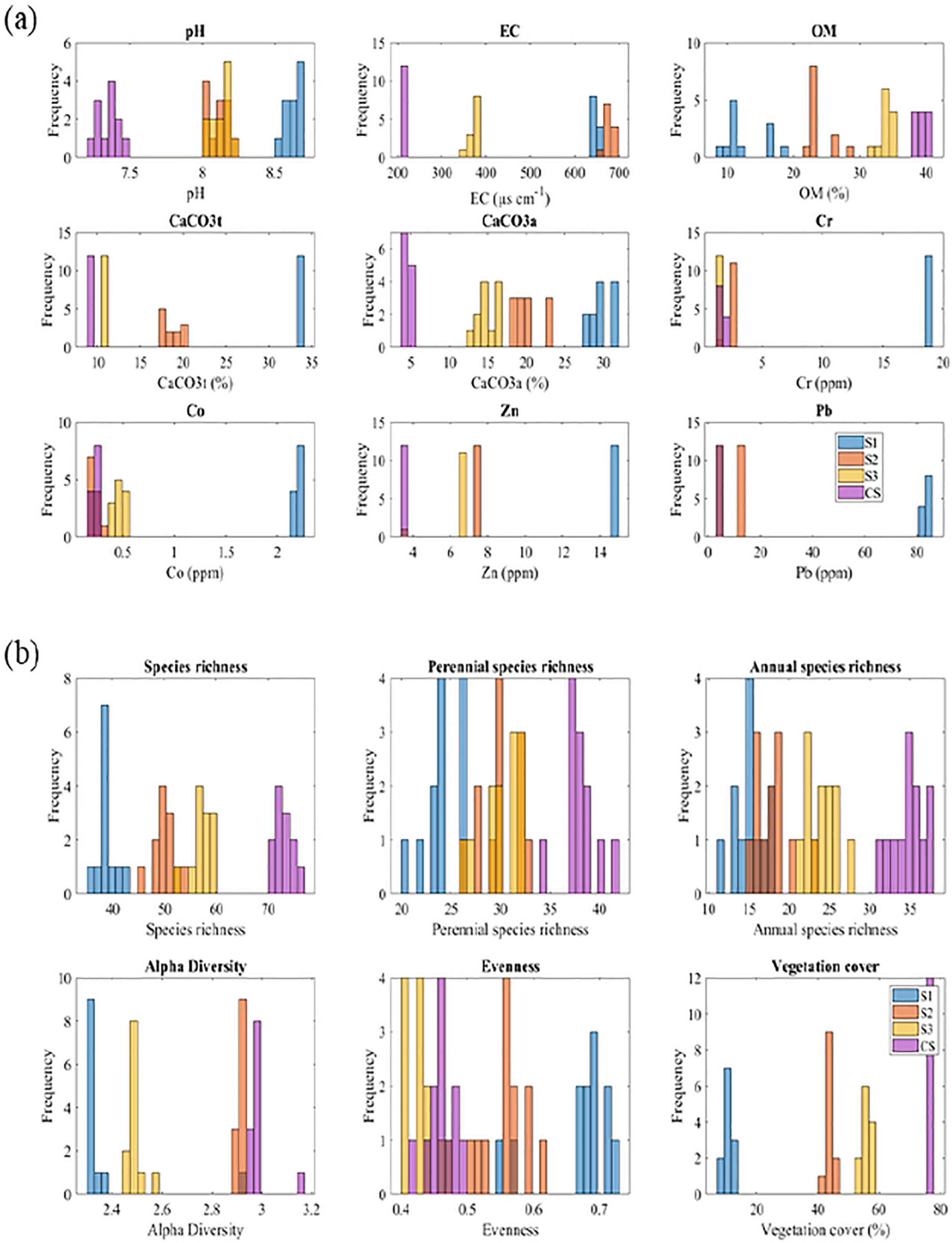

Fig. 4. Frequency distribution for (a) the soil properties and (b) the ecological indicator. Different colours correspond to subsets of data collected at diverse sites.

from the cement plant, such as EC, pH, Cr, Co and Pb. As such, PC_2^S can be interpreted as a secondary *composite descriptor of the soil state.*

Inspection of the loading factors for PC_1^I reveals even positive values of the loadings associated to the diverse original ecological indicators with exception for the negative load attributed to evenness (Fig. 5b). As such, PC_1^I can be interpreted as a composite ecological indicator describing a general 'wealthy state' of the ecosystem. Regarding PC_2^I, the largest loads were associated to the Alpha Diversity and the Evenness, which are the major helpful factors to discern between S2 and S3 (which exhibited very similar values for the Species Richness, Perennial and Annual Species Richness and Vegetation Cover, Fig.s 2). Also it is to be noted that, Alpha Diversity and the Evenness are the indicators that

Table 6
Variance, $V(\Delta)$, being Δ a given variable under analysis, and the relative percentage ascribable to the intra-site and inter-site contributes.

Δ	$V(\Delta)$	intra-sitecontribution (%)	inter-sitecontribution (%)
pH	0.21	0. 61	99.39
EC	37,888	0.05	99.95
OM	101	1.07	98.03
$CaCO_3$ t	99	0.06	99.94
CaCO3a	84	0.60	99.40
Cr	54	0.20	99.80
Co	0.68	0.60	99.40
Zn	18	0.33	99.67
Pb	1128	0.01	99.99
Species Richness	25	3.71	96.29
Perennial Species Richness	59	1.94	98.06
Annual Species Richness	0.07	3.09	96.81
Alpha Diversity	0.01	3.23	96.77
Evenness	578	0.08	99.02
Vegetation Cover	153	0.68	99.28

(contrary to the others) do not seem to vary in a regular fashion with the distance from the cement plant (Table 4).

Fig. 6 depicts (a) the observed values of the soil properties in the PC_1^S-PC_2^S plane and (b) the evaluated ecological indicators in terms of PC_1^I-PC_2^I. In Fig. 6 different colors were employed to distinguish between sites. Inspection of Fig. 6a revealed an inverse proportionality between the distance from the cement plant and the 'general level of contamination of the soil' (i.e., the values of the observations along the PC_1^S-axe). On the other hand, it can be pointed up that observations collected in S1 and SC exhibited similar values of PC_2^S, whereas observations pertaining to S2 and S3 had distinct values (i.e., PC_2^S partially captures the difference in the soil compositions of S2 and S3 which were not encoded in PC_1^S). Inspection of Fig. 6b highlights the tendency of the general level of wealthiness of the ecosystem (i.e., the recorded value of the PC_1^I for the diverse observations) to increase for those sites which lay at a greater distance from the cement plant. At the same time, considering the values of the PC_2^I, it has been noted (*i*) a similarity for the observations associated to S1 and to SC and (*ii*) a clear discrepancy between the data collected at S2 and S3 which, in turn, do not have very different values of PC_1^I.

Then, a meaningful model capable to capture eventual dependence between (PC_1^S-PC_1^S) and each of PCs of the ecological indicator was sought. In order to do so, different polynomial expressions were tested (encompasses all the possible combinations involving polynomial up to degree two) evaluating their (i) goodness of fit by means of the ensuing negative log-likelihood (Carrera and Neumann, 1986) (assuming an error on the values of the observations equals to 1%) and (ii) the corresponding model score through diverse model discrimination criteria (i.e., *AIC* by Akaike, 1974; *AICc* by Hurvich and Tsai, 1989; *BIC* by Schwarz, 1978). The latter criterions allowed to discern the most relevant model (within a set of tested model) by aiding to the goodness of fit aspect a penalization factor proportional to the number of degrees of freedom of each model (i.e., number polynomials in our case). Considering the dependence of PC_1^Iupon (PC_1^S-PC_1^S), the model with the best scores for all the model discrimination criteria was found out that proposing a simple bilinear expression of the kind

$$PC_1^I = -0.74PC_1^S - 0.29PC_2^S \quad (7)$$

Fig. 7a depicts the prediction of the selected model for PC_1^I jointly with the available observations, revealing the goodness of fit for the expression (2) (i.e., R^2 = 0.97 and RMSE = 0.45). Inspection of (2) revealed that the behavior of the identified model agreed with our general expectation, according to which as the 'general level of contamination of the soil site' decreased (i.e., PC_1^S decreased) the overall wealthiness of the ecosystem increased (i.e., PC_1^I increased). The same trend was noted with respect to PC_2^S (the secondary composite soil property), even though PC_1^I was less sensitive to the values of the latter (i.e., in (2) the coefficient associate with PC_2^S was smaller than that associated to PC_1^S). Recalling here that, both PC_1^I and PC_1^S are principal components constituted mainly by those variables (either ecological indicators and soil properties) that varied in a regular fashion with the distance from the cement plant. Meaningfully, it can be perceived that the major factor driving the structure of model (2) is the distance from the cement plant which leaded to have less contaminated soils (at least according to the general representation provided by PC_1^S) and in turn more wealthy ecosystem (at least according to the general representation provided by PC_1^I). At the same time, the secondary composite soil property (i.e., PC_2^S which didn't vary regularly with the distance from the cement plant) had a less relevant role in the determination of the general level of the ecosystem wealthiness.

On the other hand, the best model identified to capture the dependence PC_2^I upon (PC_1^S-PC_1^S) reads

$$PC_2^I = 0.03PC_1^S + 0.22PC_2^S \quad (8)$$

Fig. 7b depicts the predictions of expression (3), together with available observations: a poor match between (3) and the observations was noted (i.e., $R^2 = 0.08$ and RMSE = 0.78). The latter behavior can be interpreted as the incapability of predicting the level of Alpha Diversity and Evenness of an ecosystem (i.e., PC_2^I, which had the largest loads for the latter indicators) through the measured soil properties (as combined then in PC_1^S and PC_1^S). In other words, the variations of the values of PC_2^I across sites were to be ascribed to external factors that had not been taken into account in the current analysis (e.g., temperature, rain).

4. Discussion

Plants response to pollutants has no longer been restricted to its influence on the morphological, biochemical, and physiological traits. However, the distribution patterns, associative groups and vegetation cover are thorough indicators for assessing pollutants (Rai , 2016). Species richness variability was used to be correlated to temperature, water availability and environmental heterogeneity. In fact, pollution is a major disturbing factor affecting environmental heterogeneity. Hence it could contribute to reshape the species richness (Pausas and Austin, 2001). An increasing of simultaneously annual and perennial species richness along the distant sites (Fig. 2.c) indicates both healthier community in distant sites and land degradation in the cement plant closeness. A similar study conducted by Blanáret al. (2019) showed species richness have been fluctuated along a pollutant gradient as well as the species diversity. In accordance with our results, Boutin and Carpenter, (2017) demonstrated a dissimilarity in species richness and composition which varied significantly from sites polluted with PAH and heavy metals to less polluted sites. In our current research, a tremendous dominance of perennial species in all the studied sites was revealed. The low annual densities in S1 and S2 would be explained by the effect of atmospheric emissions near to the cement plant. Annual plant species are sensitive to sulfur (Graeub, 1988) which is a major component of cement dust. Similarly, strong dust emission induces clumps desiccation and increases stalks weakening; thus, plant photosynthesis and vitality would be affected by stomatal closure (Rai, 2016). The cement plant vicinity was characterized by the lowest rate of perennial species richness. The decline of perennial species is a reliable indicator of vegetation cover degradation (Belgacem et al., 2011). Admitting the absence of any other anthropogenic or biotic stress except the cement plant pollution where access to the surrounding areas was banned, the cement dust is formed in a major part by particulates released during cement production. This latter is an alkaline material containing heavy metals and metalloids such as Zn, Cu, Fe, Cd, Pb, and Cr. The latter are transferred to

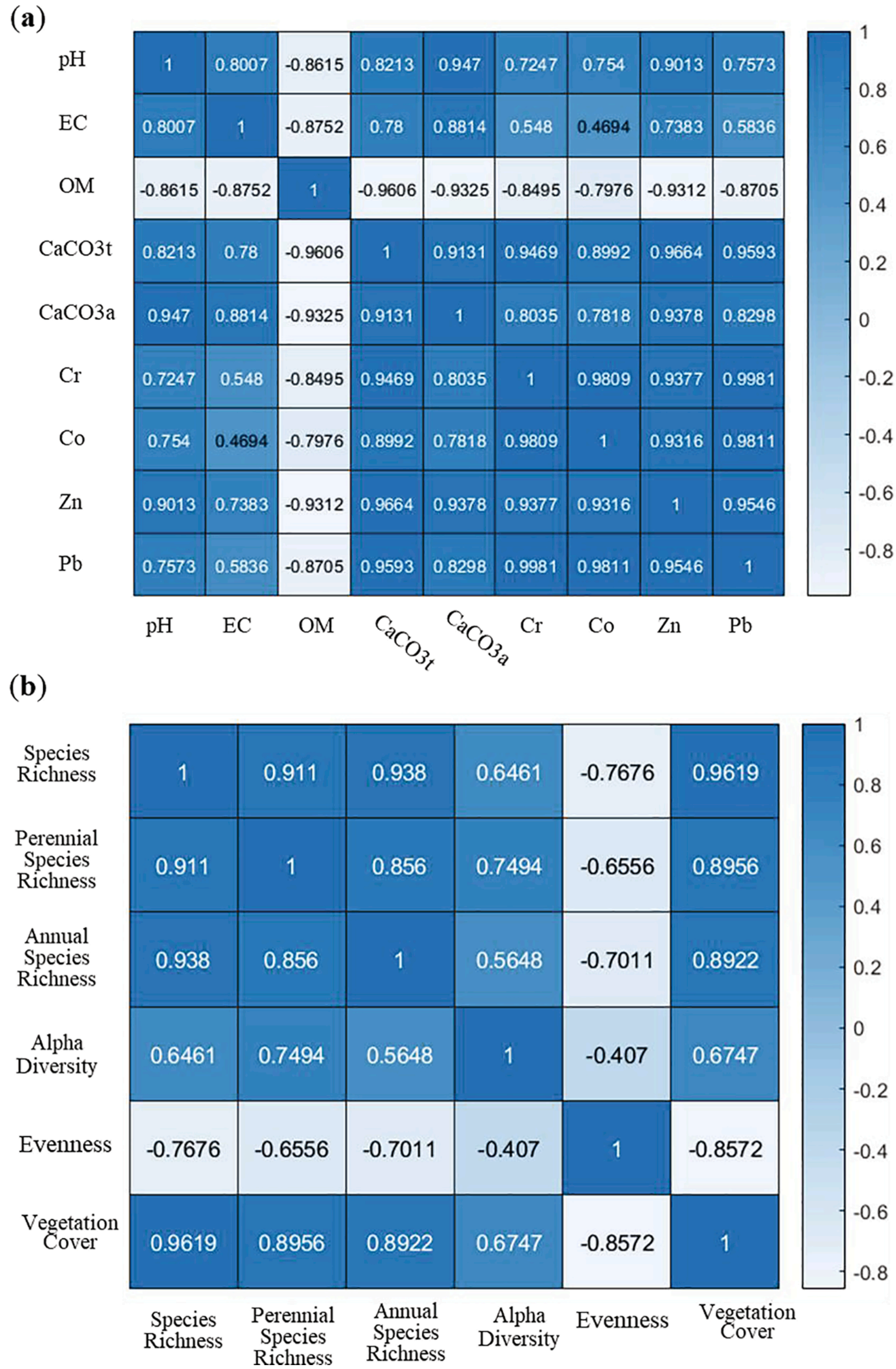

Fig. 5. Values of the linear correlation coefficient for pairs of (a) the soil properties and (b) the ecological indicator.

plant material either by a direct deposition on leaves or mostly deposited on soil and adsorbed on plant roots, harming thus, the survival of plant (Silva et al., 2015). Moreover, the type of soil is a determinant factor for species distribution. In our case the soil was of gypsum limestone outcrop type. Indeed, in some chalk phytocenoses, the dominance of perennial species over annuals was explained by a greater ability of flora to use sustainable resources when no disturbance factor is occurring, also, perennial species are more able to colonize bare soil through the lateral spread of tufts as detailed by Dutoit and Alard, (1996).

Few studies have focused on the pollution impact on flora structure particularly the difference between annual and perennial species. High sensitivity of annual species to ozone in the Iberian peninsula have been associated to strong variation in their growth and biomass (Gimeno et al, 2004). Honour et al. (2009) evidenced higher sensitivity to pollution of annual species tracked by a strong decrease in growth rate compared to other species like *C. album* and *S. oleraceus*. Furthermore, Van Goethem et al. (2013) assessed a greater biomass reduction which has been attributed to annual species against perennial grassland species in response of ozone exposure. The tolerance of perennials could be relevant to their morphology and their protected life forms. In fact, meristems of perennials are underground as rhizomes, bulbs or tubers which procure a protection against pollutants. Thus, Barett and Bush (1991) claims that life forms with subterranean organs are better able to resist the pollutant stress. Moreover, sensitivity of annual species to pollution may be attributed to their short life cycle from germination to reproduction under pollution pressure.

Table 7
Loading factors for the first two principal component of the soil properties and the ecological indicators.

Original Variable	PC_1^S	PC_2^S	Original Variable	PC_1^I	PC_2^I
pH	0.32	0.26	Species Richness	0.44	−0.08
EC	0.28	0.63	Perennial Species Richness	0.43	0.21
OM	−0.34	−0.17	Annual Species Richness	0.42	−0.13
$CaCO_3$ t	0.35	−0.04	Alpha Diversity	0.33	0.78
CaCO3a	0.34	0.25	Evenness	−0.37	0.56
Cr	0.33	−0.37	Vegetation Cover	0.45	−0.12
Co	0.32	−0.43			
Zn	0.35	−0.06			
Pb	0.32	−0.33			

The vegetation cover has been widely used as indicator for ecosystem health and a tracker of climate change as well as pollution. Several studies have reported either a decrease or an increase of vegetation cover over environmental changes within a spatio-temporal scale (De la Barrera and Henríquez, 2017; Shen et al., 2018; Zhang et al., 2018; Ortega-Rosaset al., 2020). The raising vegetation cover percentages when moving away from S1 indicates cover degradation in S1 as well as a decrease in species number based on a pollution gradient. The first site was subjected to cement dust pollution for more than thirteen years. In consequence, a decrease in vegetation cover percentage is noted in comparison with the control site. Indeed, extension of anthropogenic and industrial areas leaded to the vegetation cover decline from 58.41% to 50% in Wuhan city, China (Chen al, 2011). The variation in the vegetation cover percentage between S1 and SC could be also linked to the spatial distribution of precipitation which are pollutants transporters. Moreover, vegetation cover plays a key role in extracting environmental and ecological changes drivers (Chen et al., 2011).

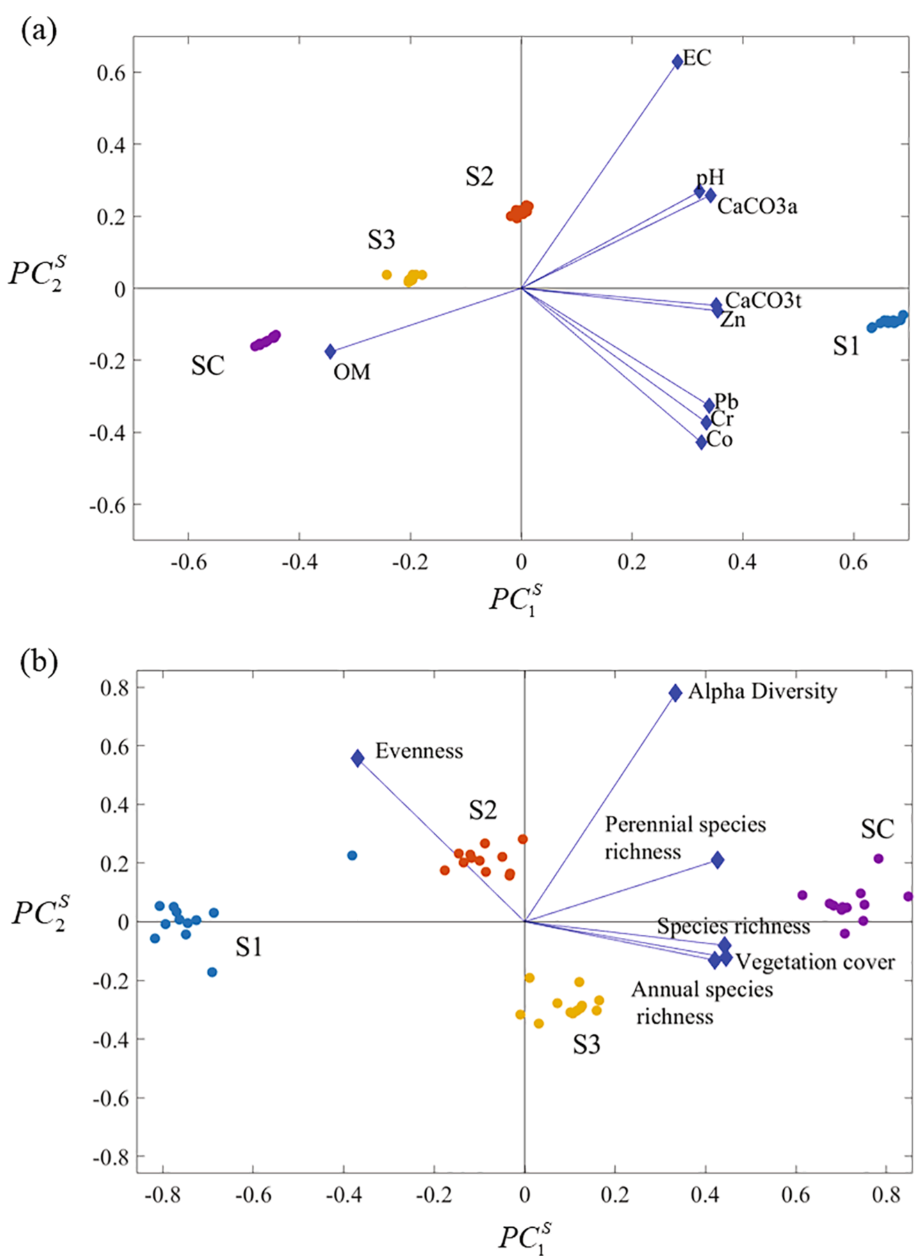

Fig. 6. (a) Available observations of the soil properties in the plane of the corresponding first two Principal Components, i.e., PC_1^S- PC_2^S. (b) Available values of the ecological indicators in the PC_1^I- PC_2^I plane. Different sites are indicated with different colors.

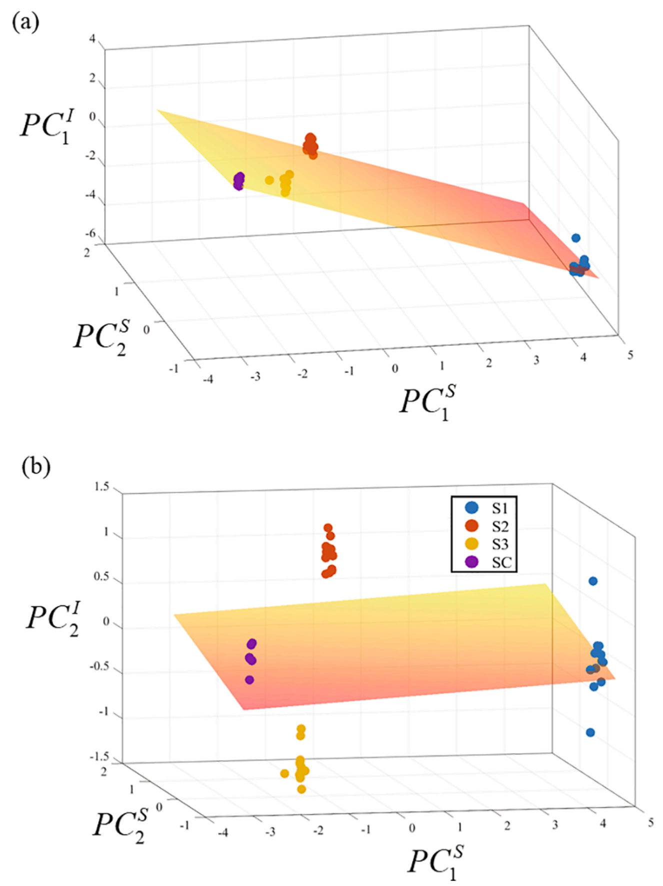

Fig. 7. Identified model to related (PC_1^S-PC_2^S) and (a) PC_1^I (see also (2)) and (b) PC_2^I (see also (3)). Available observations are also reported as circles, sites distinguished by color.'

Variability and environmental patterns occurring at different levels of organisation have to be explored in terms of bioindicators. The environmental heterogeneity associated to climate variables controls deeply ecosystem property being species richness, alpha and beta diversity and indicators species frequency. Indeed, bioindication tools are pertinent for assessing in-between sites variability. The evaluation of community patterns has been expressed as alpha-diversity along a gradient of pollution from S1 to SC. The α-diversity was assessed by Shannon and Wiener index. Recalling that, the diversity index ranges from a maximum when each species appears at a site with the same relative frequency to a minimum, when only one species is encountered (Edward et al., 1998), this diversity index was higher (2.99) in SC than other sites. This latter behaviour is likely due to an increasing of novel species in the control site. These species could be sensitive to pollutants (e.g. *Helianthemum kahiricum*, *Stipa tenassissima, Plantago coronopus*) than other species. Species growing in the distant sites could be sensitive to pollutant cement dust. Thus, their occurrence in the control site enrich the site diversity. The low evenness in the SC could reflect more heterogeneous system. Few studies have investigated changes in plant communities according to anthropogenic gradient. It has been found that lichen diversity was affected in industrial than forested areas. Also, water treatment of plants has reduced alpha diversity in downstream location compared to other locations (Giordani et al., 2014; Lencioni et al., 2020).

The beta diversity is a prominent indicator used for plant biomonitoring. Beta diversity patterns underlies community composition. Species regeneration, resilience or loss are spotted at this level. Jaccard Index indicates high differences in plant species diversity in the control site compared to the sites S2 and S3. This would confirm the conceptual distribution of potential sensitive and tolerant species.

Some species had the ability to colonize close areas to the plant such as *G. decander, L. spartum* and *A. serratuloides.* The latter exhibited a tolerance to the atmospheric pollutant effect and was distributed along the four investigated sites. Other species such as *A. herba alba*, *H. kahiricum* appeared save in the third site reflecting a high sensitivity to disturbing environment. Heavy metals as well as the large amount of Ca reaching the leaves, lead to stomatal obliteration (Baciset al., 1999). Moreover, land degradation underlies a disturbed vegetation dynamic characterized by a decrease of perennial species and a fragmentation of floristic composition (Hanafi and Jauffret, 2008).

The vegetation surrounding areas is a mining source of tolerant species. These species could be operating as sinks for pollutants (Davis et al, 2016). Exploration of the plant species abundance in the site close to the cement plant identified five potential tolerant species. The investigation yielded *L. spartum*, *A. serratuloides*, *G. decander*, *E. glaucophyllum* and *H. kahirikum*. Examination of potential plant species throughout heavy metals bioaccumulation and translocation factors exhibited higher MTF and MBF in perennial against annual species. Perennial species were shortlisted for phytoremediation target. Indeed, *L. spartum* and *A. serratuloides* belonging to Poaceae family were species that are spreading spontaneously in semi-arid Mediterranean areas. *L. spartum* showed high MBF > 1 and MTF > 1. It was documented that plant species having an MTF > 1 and MBF > 1 where their aboveground heavy metals concentrations are comparable to theirs in the soil, are heavy metals bioindicators (Sawidis et al, 2011). *L. spartum* could be an indicator of heavy metals pollution having the highest MTF and MBF. This species could tolerate arid, saline, and extreme warm conditions (Conesa et al., 2007). This species was selected in a study conducted by Bayouli et al., 2020 and was investigated for accumulation potential and phytoremediation targets. Indeed, it was able to sequester heavy metals such as Cu, and Cd. Furthermore, *G. decander* revealed as bioindicator (MTF > 1), this species belonging to Caryophyllaceae family was considered for many studies as rehabilitant species beneath the canopy (El-Banaet al., 2010; Liancourt and Tielbörger, 2011). This species adapts to Mediterranean climate and is wide abundant in arid environments. Furthermore, it has a great positive effect on plants by facilitating growth and biomass production of endemic Mediterranean species especially in arid to pre-saharian environments. Its presence was linked to a high density of annual species underneath it. Consequently, in the environment where stresses were induced, the annual species growth would appear. It can be concluded that the closest areas to the cement plant were more subjected to cement dust pollution initiating cover degradation. As a result, the cover replies through a tendency to upgrade density of annual species. To remediate to such structural disturbance, *G. decander* stood as promoter to strengthen the perennial species proliferation the noteworthy of healthy vegetation cover. With morphological traits adapted to arid conditions, this shrub of 10 to 35 cm of length developing small and succulent leaves was generally favoring gypsum soils as previously demonstrated in the Southeastern of Tunisia (Moussa, 2016). It could be mentioned that gypsum medium is chemically composed of Ca that featured as main component in the cement manufacturing usually installed on limestone quarry. This would strongly suggest that gypseum limestone soil type in the vicinity of the cement plant was a rewarding factor for *G. decander* sprouting.

Among the species encountered along the four sites, *A. serratuloides* (Astericaceae family), was found in arid regions of Tunisia associated or not with other species. This species could be an indicator with high MTF and MBF > 1. A study reported by Boukhris et al, 2015 confirmed its ability to cope with polluted sites, presenting the ability to house areas near pollution with high ecological amplitude and an extended distribution. A particularity fitting out this statement was that this species was less to blank palatable. This fact played a discriminant role in the regeneration and rehabilitation of degraded regions wherein lost species were replaced by other species like *A. serratuloides* (Benaradj et al., 2013). All identified indicators species in the industrial areas could be considered as a sink of pollutants which can reduce pollutant concentration by accumulating contaminants in their roots and aerial parts. This species could be employed for phytomanagement process of contaminated areas by facilitating heavy metals flux from soil to plant system, remediating, therefore, the soil.

Monitoring ecological alongside economic indicators underpins spatio-temporal management actions and direct policy makers to a straightforward operation. Environmental assessment at different scales of organization combines indicators at individual, community, ecosystem, and landscape levels; thereby, expanding the dimension for understanding the ecosystem (Doren et al., 2009; O'Brien et al., 2016). Given that ecological indicators are mirroring ecosystem health, evaluating these indicators appraises many outcomes which relay on extracting causes and subsequent repercussions specifically those degrading ecological health. In a preventive measure, that is further cost-effective than later established remediation management. Besides, effectiveness and robustness for the already inaugurated management are of equal goal for the future health quality management (Angermeier and Karr, 2019). Biomonitoring of ecological indicators at multiscale assessment has been developed with respect to several researches (Shanley et al., 2013; Beauchard et al., 2017), indicators goodness have been systematically discerned. Advanced researches subtracted relevant ecological indicators to the pollution exposure indicators such as modelled pollutant concentration in soil, in addition to the response indicators forecasting the biological integrity estimated mostly at different scale of biological organization such as taxa richness, biodiversity multimeric indexes (Angermeier and Karr, 2019). Only few data are provided for the Mediterranean region which has been subjected to a massive load of atmospheric pollutants. An appealing need for synergistic actions and strategies that quantify response indicators including biodiversity indicators to foreground its socio-ecological outcomes has been recently launched (Ochoa-Hueso et al., 2017). In response to this need, the current research introduced the vegetation response indicators where they were statistically robust for diagnosing the problem and detecting spatial trends driving the ecological patterns that were more explained at individual and ecosystem levels. This latter redesigns a proportionality with biological integrity broadening intersections between ecologically abundant and chemically tolerant species. Consequently, indicators were cost-effective allowing minimizing relative spatio-temporal sampling costs. That also downgrades uncertainties by limiting potential spatial boundaries for the targeted group at different scales prior to remediation management. Although, indicators could be sensitive to an identified stressor but not limited to since many indicators could be also sensitive to unidentified stressors. Recalling in this current study that evenness representing one of the indicators that was not driven by pollution in contrast to the other indicators.

5. Conclusion

The cement plant pollution impact on the vegetation cover have been diagnosed through macroecological indicators. Species richness tracked a decrease in the close site S1 compared to the control. The vegetation cover has tremendously increased by around 7 times from S1 to SC. Species density have significantly increased between the closest site to the control site. These ecological attributes allowed the identification of a list of annual sensitive species such as *P. coronopus*, *P. arabica*, *E. retusa* and sensitive perennial species as *A. armatus*, *Artemisia herba alba*, *H. kahiricum* were identified in the control site. The prominent feat is the expansion of pollutant-tolerant species such as *A. seratuloides*, *L. spartum* and *G. decander* which exhibited a great ability to cope with pollution disturbances, could be useful for sink-trap species and offer their possible use in phytoremediation perspectives in a context of sustainable development.

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CRediT authorship contribution statement

Ines Terwayet Bayouli: Methodology, Formal analysis, Investigation, Resources, Writing - original draft, Project administration, Funding acquisition. **Houssem Terwayet Beyouli:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision. **Aronne Dell'Oca:** Formal analysis, Writing - review & editing. **Erik Meers:** Conceptualization, Formal analysis, Writing - review & editing, Supervision. **Jian Sun:** Formal analysis, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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