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Original article

Environmental pollution: Assessment of concentration of heavy metals in soil, plant and insects in the vicinity of the factories of 10th of Ramadan City (Sharqeya, Egypt)

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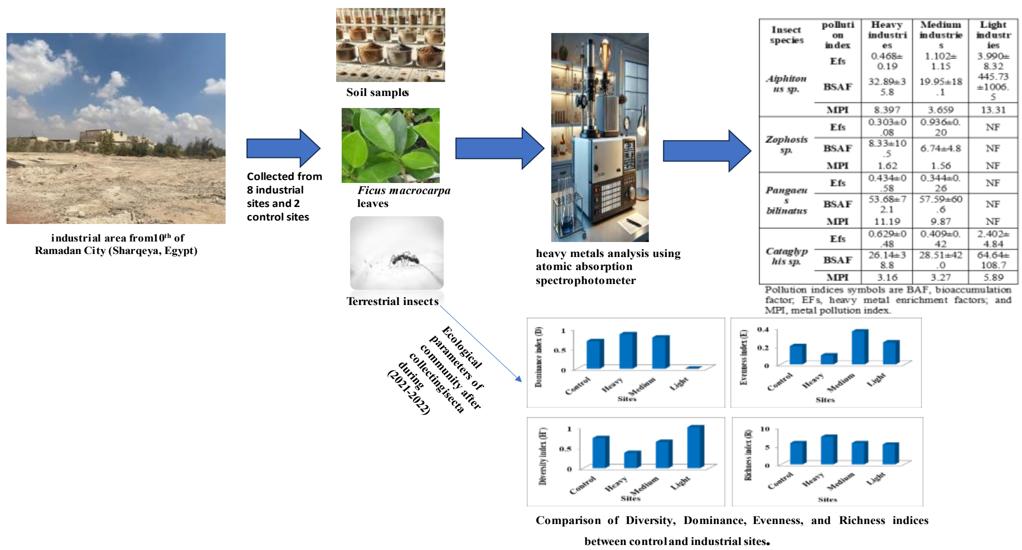
ABSTRACT

Industrial pollution is considered one of the most dangerous factors threatening the environment (soil, plants, insects, etc) and human health. Terrestrial insects are used as bioindicators for heavy metal contaminants in different industrial areas. Therefore, the current work aims to study the accumulation of heavy metals (Manganese, Zinc, Copper, Iron, cadmium, and Lead) in *Cataglyphis* sp. (Hymenoptera: Formicidae), *Zophosis* sp. (Coleoptera: Tenebrionidae), *Alphitobius* sp. (Coleoptera: Tenebrionidae), and *Pangaeus bilineatus* (Hemiptera: cynidae), and in soil and *Ficus macrocarpa* leaves sampled from 10th of Ramadan city (Sharqeya, Egypt). Ten study areas were selected and classified as follows: Heavy industries (A) (three sites), medium industries (B) (three sites), light industries (C) (two sites), and control sites (D) (two sites). The pollution levels were evaluated by Enrichment factors (EFs), Bioaccumulation factor of sediment (BAF), and Pollution index (MPI), which showed a variable metallic polluted state. The highest concentrations of metals were found in soil samples and leaves of *Ficus macrocarpa* leaves which were sampled from light industrial sites. Iron (Fe) and Zinc (Zn) were the most accumulated elements in the collected insects. A correlation between the levels of metals was found in the soil and insects. The present investigation showed that terrestrial insects showed patterns of site-specific metal accumulation and that insects belonging to Order: Hemiptera can accumulate more heavy metals than others.

Graphical abstract



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1. Introduction

The Industrial Revolution and technological development have been the main human influence on natural ecosystems since the eighteenth century [34]. Heavy metals and other harmful substances released into the atmosphere may have irreversible and unpredictable environmental effects and cause severe global pollution [80, 19]. Heavy metals are ranked among the most hazardous anthropogenic environmental pollutants due to their toxicity to biota, inability to be broken down chemically or biologically, ability to stay in the environment, and ability to accumulate in all ecosystems, including the human body [22, 27, 45]. Not all heavy metals are harmful, but some are essential for human biological systems. On the other hand, non-essential elements are poisonous to living things, even in trace amounts [4, 62].

Soil is an excellent indicator of environmental quality, bed storage for contaminants, and an accumulator of heavy metals [18]. A significant portion of heavy metal research has focused on heavy metals deposition and permanence in the soil, their transport through the food chain, and their relationship to the sustainability of ecological systems [84, 63]. Many researchers have investigated the extent of industrial pollution and the build-up of heavy metals in soil at various industrial locations and found that soil is an effective tracer for industrial emissions [84, 63, 26].

On the other hand, plants may absorb heavy metals from the soil excessively, which may become hazardous [59] and move up the food chain [84, 63]. Because heavy metals accumulate, particularly in the tissues and fluids of plants, plants view this as an "early-warning" signal of stress symptoms brought on by pollution [8]. So, it seems to have great promise in eliminating contaminants from the environment and might be employed as bioindicators for evaluating pollution levels [25, 81].

Insects are a more useful ecological tool for assessing environmental changes than other organisms in any habitat. Because of their higher impact on terrestrial ecosystems and a high degree of diversity [24, 66]. An insect's entire body has more concentration of metal buildup than just one organ [12]. Among the most popular and widespread terrestrial insects in any ecosystem are the ants [7, 75], and beetles [6, 65, 86]. Also, Order Hemiptera tends to accumulate heavy metals, making them suitable as biomonitors for heavy metal pollution [40].

Changes in biogeochemical cycles, primary productivity, changed biotic interactions, and diminished ecosystem resilience are examples of long-term effects of heavy metals pollution. So, measuring species richness or individual species abundance is key to detecting environmental effects [39]. Studies on how pollution affected the diversity of certain insects discovered that pollution in the environment also influences the diversity of different insect species [36, 46, 38]. Climate change also affects the insect species population [38]. Therefore, the current study was conducted to survey terrestrial insects at different industrial localities according to their type of industries compared to natural localities for four successive seasons. Also, to estimate the heavy metals in soil and flora as the bed reservoir in habitat, and to assess the spatial scale of bioaccumulation levels and indices.

2. Materials and methods

2.1. Study area

The 10th of Ramadan city is situated on the Cairo-Ismailia desert road (55.82 km west-southwest from Cairo in Al Sharqia governorate, Egypt.) is considered one of the first and largest industrial cities that appeared in the past forty years [89]. It covers an area of around 465 km^2 and its Geographical coordinates are, latitude 30° 18' 8" N, 31° 44' 44 " E (Figure 1). It is bounded by El Shabab Canal from the east, El Asher-Belbes road from the west, the Ismailia Canal from the north, and the Cairo-Ismailia desert road from the south. The city's location in the desert region east of the Delta has an impact on the climate where it is located in a desert climate, the temperature rises, the relative humidity decreases, and the amount of precipitation decreases [32].

The most common industries differ between heavy industries such as iron and steel industries, ceramic industry, electrical cable manufacturing and electrical products, medium industries such as the pharmaceutical industry, plastic industries, oil, and fat industry and finally light industries which contain a large number of small factories most of these which are food and drinking industries and others such as textile industries, smoke industries, engine oil factories and manufacture of packaging products[89]. Ten locations were selected to provide the best possible representation of the bioaccumulation state of heavy metals throughout the city. Heavy (A) and medium industries (B) are represented by three sites, light industries (C) are represented by two sites, and control sites (D) are also represented by two sites away from the industries site.

2.2 Insect collection

During (2021 -2022), ground insect sampling was carried out for four successive seasons (i.e. autumn, winter, spring, and summer) at several selected study sites, employing the widely known and useful pitfall trap sampling method [52, 44]. The specimens obtained were taxonomically identified. For further identification and counting, the sample species were preserved using a 70% ethylene glycol solution [51].

2.3. Soil, plant and insect sampling for heavy metals analysis

2.3.1. soil

Soil samples were collected from 10 study sites. the soil samples were collected at 10 cm depth according to Laura et al. [50], where anthropogenic heavy metals are typically deposited on topsoil and labeled based on the kinds of industries: heavy industries (A), medium industries (B), light industries (C) and control sites (D). The samples were taken to the lab to be cleaned and air-dried, and a small section of less than 2 mm was placed in a bag for additional heavy metal analysis [13]. The heavy metals in the soil estimation protocol were summed up according to Quevauviller et al. [71] and Vercoutere et al. [83].

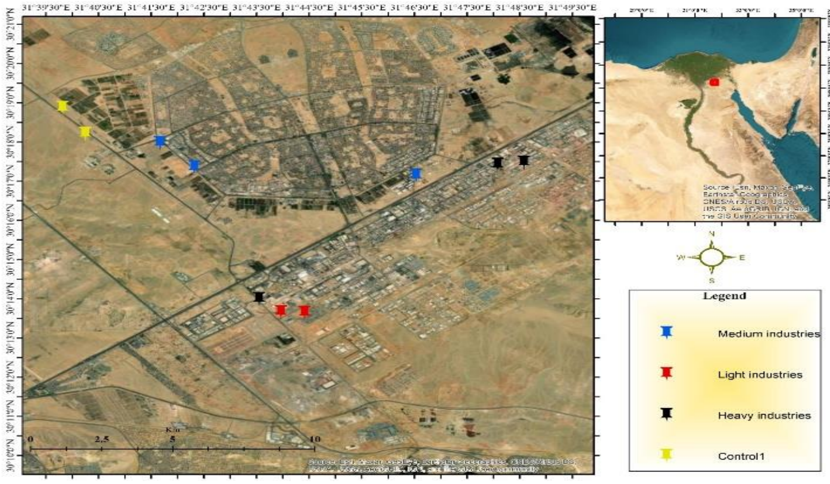

Figure 1: Map of the geographical location of the study area and sampling sites in 10th of Ramadan city, Sharqeya governorate, Egypt.

2.3.2 Plants

The most common plant in almost all study sites was *Ficus macrocarpa* (Family: Moraceae) it was identified according to Boulos [10]. This makes it a suitable option for detecting heavy metals in the study area. Separate plant samples were gathered from various locations, cleaned, and dried using plant press. The plant sample was ground and then kept apart for examination of heavy metals as stated by Insect Keys [33] using an atomic absorption spectrophotometer.

2.3.3. Insects

Based on the survey conducted in the study area, insect species belonging to four genera within 3 orders were selected for heavy metals analysis i.e. *Cataglyphis* sp. (Hymenoptera: Formicidae), *Zophosis* sp. (Coleoptera: Tenebrionidae), *Alphitobius* sp. (Coleoptera: Tenebrionidae), and *Pangaeus* (Hemiptera: cynidae). The collected specimens were identified by using a taxonomic key [33], photos, and experts in the taxonomy of Hymenoptera [31], Coleoptera [14, 15] Coleoptera [9], and Neuroptera [50]. According to Hamza [88] protocol 0.25 g of the entire insect body weighed from whole insect body was carried out by electric balance (4 digital) and used for heavy metals analysis using an atomic absorption spectrophotometer (GBC AVANTA™) at Theodor Bilharz Research Institute according to Moon et al. [60].

2.4. Ecological parameters of community

2.4.1. Simpson diversity index

Simpson diversity index is the most tractable and statistically useful calculation for the dominance index as follows:

$$D = \sum (pi)^2$$

Where D is the dominance index, ∑ is the sum, pi = (ni/N) is the ratio between ni = Number of individuals of a species and N =Total individuals of all species in the biological community [85], the most commonly used diversity index is the Shannon-Weiner index, which was calculated as follows:

$$H' = -\sum pi \ln pi$$

Where H' is the Diversity index, pi = (ni/N), and ln is the natural logarithm [67], The used formula of Pielou [68] is as follows:

$$E = H' / \ln(S)$$

Where H' is the Diversity index, ln is the natural logarithm, and S is the Number of species found to calculate the evenness index, and the richness index (R) was calculated using the [58] equation as follows:

$$R=(S-1) *(1)/ \ln(N)$$

Where R is an index of species richness, S is a number of species observed, N is the number of observed individuals, ln is the natural logarithm.

2.4.2. Pollution indices

Heavy metal enrichment factors (Fes) index was calculated according to Ajerrar et al. [2] equation as follows:

$$EF = (Cx/CFe)\ Sample/(Cx/CFe)$$

Where (Cx/CFe) Sample is the ratio of the content of the element and the content of Fe in the sample. While (Cx/CFe) reference is the ratio of the same element and the content of Fe in natural habitat as reference. The biota-sediment accumulation factor (BSAF) was calculated according to Lau et al. [49] and Szefer et al. [77] as follows:

$$BSAF = Ct/Cs$$

Where Ct = tissue concentration (mg/g tissue), and Cs = sediment concentration (mg/g) and the metal pollution index (MPI) was done based on the equation of Usero et al. [82]:

$$MPI=(Cf1\times Cf2\cdots\cdots Cfk)\ 1/k$$

Where Cf1 is the concentration value of the first metal, Cf2 is the concentration value of the second metal; Cfk is the concentration value of the k th metal, K, number of metals.

2.4.3. Statistical analysis

All data of heavy metals determined in the plant, soil, and insects were presented as mean ± sd and compared between all groups (the control, heavy, medium, and light industrial sites) using One-way ANOVA at $p < 0.05$. Canonical correspondence analysis (CCA) was used to describe the correlation between the distribution of insect species at different study areas and heavy metal concentrations.

3. Results

3.1. insect survey, diversity and relative abundance.

A total of 2939 insect individuals belonging to 15 species were collected from the study sites (Table 1). The most common species in all studied sites belonged to the species of the genus *Cataglyphis* sp., followed by species of the genus *Zophosis* sp. Results in Figure (2) showed that Formicidae was the dominant family in the control sites recorded (88 %), followed by Tenebrionidae (7 %) and Cydnidae (3 %), then Carabidae (2 %). Also, Formicidae and Tenebrionidae families were the most dominant in all industrial sites, as shown in Figure (2). So, the control sites have the highest number of families compared to the other industrial sites.

The highest species richness value was recorded at High industrial sites (7.5), light industries sites showed the maximal value of diversity index (1.0) and minimum value of dominance index (0.003) and Heavy industrial sites showed the minimum value (0.1), as shown in Table (1) and Figure (3).

3.2. Seasonal fluctuation

As shown in Table (2) Autumn represents the highest value of dominance index (0.92), also summer represents the highest value of diversity (0.91) and evenness index (0.43), while the highest value of richness index was shown in spring (3.36). On the other hand, winter represents the lowest value of the richness index (2.62).

3.3. Heavy metals in soil, plants and insects:

Data in Table (3) shows the amount of six heavy metals (Manganese (Mn), Zinc (Zn), Copper (Cu), Iron (Fe), cadmium (Cd), and Lead (Pb) measured in the soil samples and *Ficus macrocarpa* leaves collected from the different sites in the 10th Ramadan District. In industrial sites, the highest value of heavy metals in soil was recorded in light industrial sites (107.54 mg/g) followed by heavy sites (79.14 mg/g) and the lowest site recorded heavy metals was medium sites (74.72 mg/g) but in plant leaves the highest value of heavy metals was recorded in light industrial sites (133.73 mg/g) followed by medium sites (81.82 mg/g) and the lowest site was heavy industries (79.14 mg/g). Medium industrial sites showed the highest value of (Zinc) (16.68 ± 0.3 mg/g) in plant and (Manganese) (0.03939±0.71 mg/g), (0.02527±0.80 mg/g) in soil and plant leaves, respectively. Heavy industrial sites displayed the highest values of (Lead) in soil (0.00943 ±0.23 mg/g) and plant leaves (0.00083±0.23 mg/g).

The range of heavy metal accumulated in *Alphitobius*, *Zophosis*, *Pangaeus*, and *Cataglyphis* is shown in Table (4). *Alphitobius* collected from light industrial sites contained the highest (Fe) and (Mn) levels (8337.5 and 0.1068 mg/g, respectively), while *Zophosis* collected from the heavy industrial sites had the highest levels of the same metals (796.5 and 0.03091 mg/g, respectively). *Pangaeus* collected from the control sites showed the lowest concentration of heavy metals, while the same insect collected from heavy industrial sites showed the highest levels of (Fe), (Pb), and (Cd) (13053.8, 0.0857 and 0.5313 mg/g, respectively). Meanwhile, *Cataglyphis* collected from Light industrial sites showed the highest concentration of (Fe), (Cu), and (Pb) (1215.4, 372.2, and 0.0666 mg/g, respectively), while the same insect collected from control sites displayed the lowest concentrations of (Fe) and (Pb) (217.87 and 0.00108 mg/g, respectively).

3.4. Pollution indices

Results in **Table (5)** showed that the calculated EFs for all heavy metals determined in the insect species from industrial sites were within the normal range (0.5-1.5). Except for EFs in *Alphitobius* sp. and *Cataglyphis* sp. (3.990 and 2.402, respectively) >1.5 at Light industrial sites. Table (5) shows the calculation of the biota-sediment accumulation factor (BSAF) (Insect species/soi). The average BSAF was higher (445.73±1006.5) in *Alphitobius* sp. at light industrial sites than at the other industrial sites. On the other hand, the average BSAF values were low (8.33±10.5 and 6.74±4.8) in *Zophosis* sp. at heavy and medium industrial sites, respectively. The average BSAF values were moderate (57.59±60.6 and 53.68±72.1) in *Pangaeus* sp. at medium and heavy industrial sites, respectively. Meanwhile, the highest average BSAF value was in *Cataglyphis* sp. at light industrial sites (64.64±108.7). Data in table (5) displayed the calculation of the Metal Pollution Index (MPI). The MPI value for *Alphitobius* sp. at light industrial sites was higher than that of the other industrial sites. On the other hand, MPI values for *Cataglyphis* sp. were high in descending order as follows: light > medium > heavy industrial sites.

3.5. Canonical Corresponding Analysis (CCA)

Results in Table (6) and Figure (4) describe the correlation between the distribution of insect species at different study areas and heavy metals concentrations. The first two axes of Canonical Corresponding Analysis (CCA) explained 76.4 % of the variation in the data (Table 6). The 1st CCA showed a positive correlation between Cd (0.545) and insect species *Lapidura* sp. (1.867) and *Poecilus* sp. (1.870) at control sites. Also, *Scaurus striatus* (-0.609) and *Plaps* sp. (-0.609) showed a positive correlation with Fe (-0.937) at heavy and light industrial sites (Fig. 4). The 2nd CCA displayed a positive correlation between *Bimelia bipuncutate* (1.294) and Zn (0.781) at the medium industrial sites.

Table 1: Collected insect species from different stations in the 10th Ramadan District, Egypt (2021-2022)

Order	Family	Insect species	Insect numbers/ Sites			
			Control sites	Heavy ind. sites	Medium ind. Sites	Light ind. Sites
Neuroptera	*Myrmeleonti-dae*	*Myermeleon* sp. *(nymph)*	1	2	3	0
Hemiptera	*Cydnidae*	*Pangaeus bilinatus*	8	1	2	0
	Lygaeidae	*Spilostethus* sp.	5	10	0	2
Hymenop-tera	*Formicidae*	*Cataglyphis* sp.	270	1668	346	378
Dermaptera	*labiduridae*	*lapidura sp.*	1	0	0	0
Coleoptera	*Tenebrionidae*	*Tentyrina* sp.	0	41	6	15
	Tenebrionidae	*Zophosis* sp.	12	68	15	0
	Tenebrionidae	*Eleodes* sp.	0	6	3	2
	Tenebrionidae	*Attagenus* sp.	6	7	0	17
	Tenebrionidae	*Erodius* sp.	0	1	2	1
	Tenebrionidae	*Bimelia bipuncutate*	0	0	1	1
	Tenebrionidae	*Scaurus striatus*	0	1	12	0
	Carabidae	*Poecilus* sp.	7	0	0	0
	Tenebrionidae	*Alphitobius* sp.	2	1	2	0
	Tenebrionidae	*Plaps* sp.	13	0	0	0
		Total	325	1806	392	416
		Dominance index (D)	0.69	0.86	0.78	0.003
		Diversity index (H`)	0.734	0.376	0.641	1.0
		Evenness index (E)	0.2	0.10	0.36	0.24
		Richness index (R)	5.8	7.5	5.8	5.4

-Dominance index was (0 < D < 0.5 = Low Dominance, 0.5< D ≤ 0.75 = Moderate Dominance, 0.75< D ≤ 1.0 = High Dominance).
- Diversity index was (H` ≤ 1 = Low diversity, 1 < H`≤ 3 = Moderate diversity, H` ≥ 3 = high diversity).
- Evenness index was (0 < E ≤ 0.5 = Depressed community, 0.5 <E ≤ 0.75 = Unstable community, 0.75 <E ≤ 1 = Stable community).
- Richness index was (R < 2.5 Low species richness, 2.5 > R < 4 Medium species richness, R > 4 High species richness).

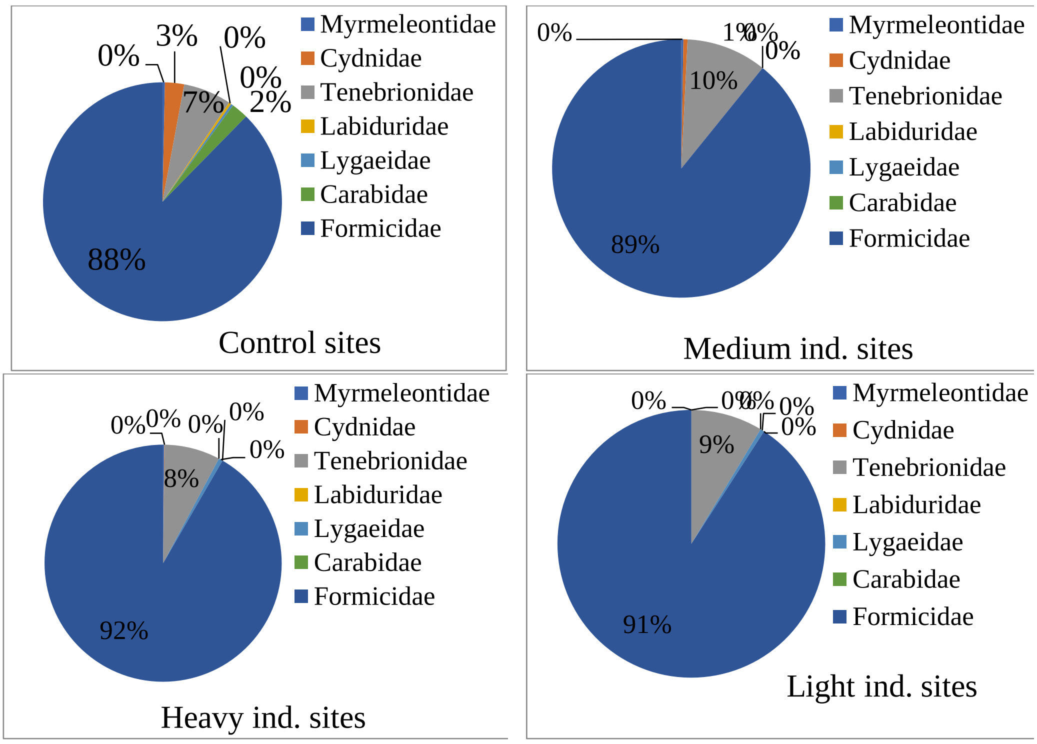

Figure 2: Percentage proportion of insect families sampled from the control and different industrial sites in the 10th Ramadan District, Egypt (2021-2022).

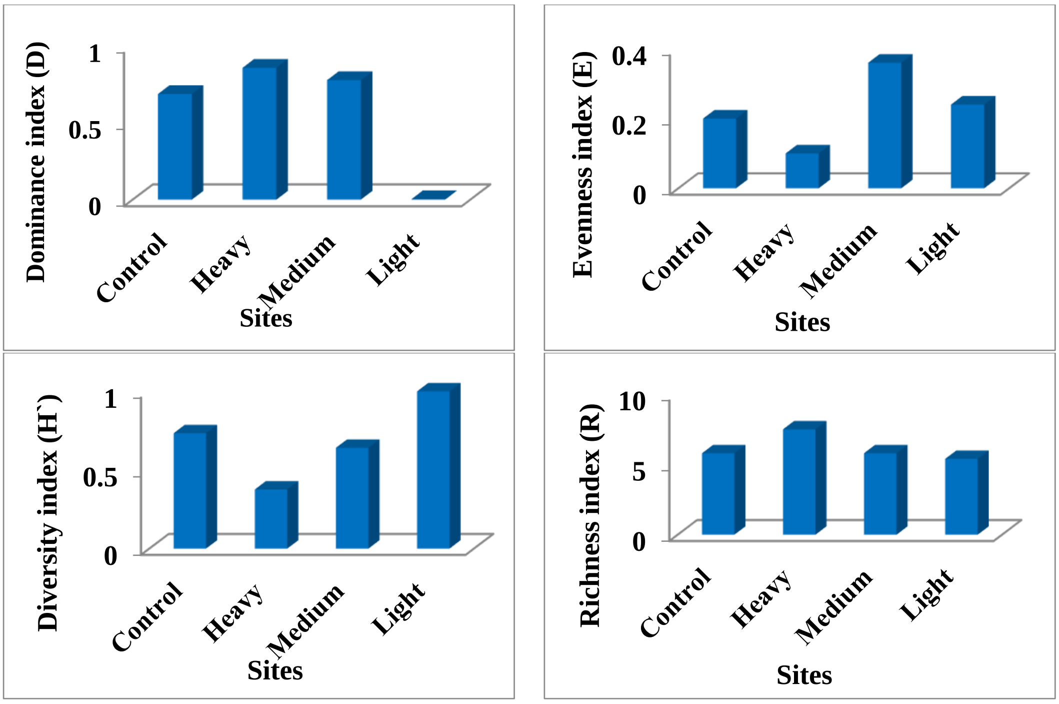

Figure 3: Comparison of Diversity, Dominance, Evenness, and Richness indices between control and industrial sites.

Table 2: The Collected insect species from different sites during four successive seasons (2021-2022) in the 10th Ramadan District, Egypt

sp. cod	Scientific name	Seasonal variation				Sum
		Summer	Winter	Spring	Autumn	
1	*Myermeleon* sp.(nymph)	3	0	0	3	6
2	*Pangaeus bilinatus*	1	0	10	0	11
3	*Tentyrina* sp.	17	0	37	8	62
4	*Zophosis* sp.	39	19	20	17	95
5	*Eleodes* sp.	5	0	2	4	11
6	*Attagenus* sp.	6	10	11	3	30
7	*Spilostethus* sp.	0	1	8	8	17
8	*Erodius* sp.	0	0	2	0	2
9	*Bimelia bipuncutate*	0	0	6	7	13
10	*Scaurus striatus*	0	1	0	0	1
11	*Lapidura* sp.	0	0	1	0	1
12	*Poecilus* sp.	0	3	0	4	7
13	*Alphitobius* sp.	0	2	2	2	6
14	*Plaps* sp.	13	0	0	2	15
15	*Cataglyphis* sp.	265	158	839	1400	2662
	SUM	349	194	938	1458	2939
	Dominance D	**0.592218**	**0.67427**	**0.809071**	**0.923479**	**0.824268**
	Simpson1-D	**0.407782**	**0.32573**	**0.190929**	**0.076521**	**0.175732**
	Diversity index H	**0.912064**	**0.713516**	**0.529474**	**0.249546**	**0.501416**
	Evenness index(E)	**0.43861**	**0.366675**	**0.220808**	**0.104069**	**0.185157**
	Richness index (R)	**2.752843**	**2.622605**	**3.364508**	**3.160798**	**4.036677**

- Dominance index was (0 < D < 0.5 = Low Dominance, 0.5< D ≤ 0.75 = Moderate Dominance, 0.75< D ≤ 1.0 = High Dominance).
- Diversity index was (H` ≤ 1 = Low diversity, 1 < H`≤ 3 = Moderate diversity, H` ≥ 3 = high diversity).
- Evenness index was (0 < E ≤ 0.5 = Depressed community, 0.5 <E ≤ 0.75 = Unstable community, 0.75 <E ≤ 1 = Stable community).
- Richness index was (R < 2.5 Low species richness, 2.5 > R < 4 Medium species richness, R > 4 High species richness).

Table 3: Spatial variations of heavy metals content determined in soil samples and in *Ficus macrocarpa* leaves samples collected from different sites in the 10th Ramadan District, Egypt (2021-2022).

Samples/ Stations		Fe (mg/g)	Zn (mg/g)	Cu (mg/g)	Pb (mg/g)	Cd (mg/g)	Mn (mg/g)	Sum (mg/g)
Soil	Control sites	21.37^{A}±0.54	56.1^{A}±0.35	32.3^{A}±0.25	0.00638^{A}±0.26	0.01450^{A}±0.60	0.02805^{A}±2.00	109.8
	Heavy ind. sites	66.35^{B}±1.50	8.86^{B}±0.151	3.89^{B}±0.20	0.00943^{B}±0.23	0.01046^{B}±0.83	0.02391^{B}±0.95	79.14
	Medium ind. sites	51.42^{C}±1.50	20.46^{C}±1.50	2.79^{C}±0.20	0.00460^{C}±0.21	0.00320^{C}±0.30	0.03939^{C}±0.71	74.72
	Light ind. sites	97.00^{D}±2.0	9.21^{B}±0.20	1.31^{D}±0.03	0.00137^{D}±0.02	0.00855^{D}±0.50	0.01551^{D}±0.70	107.54
	F-value	1345.948	206.89	99.371	265.449	187.43	199.722	-
	P- value	0.000	0.000	0.000	0.000	0.000	0.000	-
Ficus macrocarpa	Control sites	124.46^{A}±2.35	7.76^{A}±0.25	1.44^{A}±0.04	0.00043^{A}±0.01	0.01328^{A}±0.47	0.00962^{A}±1.22	133.68
	Heavy ind. sites	19.39^{B}±0.53	14.03^{B}±1.0	3.47^{B}±0.31	0.00083^{B}±0.04	0.03140^{B}±0.66	0.01442^{B}±0.52	33.94
	Medium ind. sites	62.48^{C}±0.50	16.68^{C}±0.3	2.59^{C}±0.30	0.00044^{A}±0.05	0.04647^{C}±0.87	0.02527^{C}±0.80	81.82
	Light ind. sites	116.1^{D}±2.00	14.06^{B} ±0.06	3.52^{B}±0.26	0.00025^{C}±0.03	0.03211^{B}±1.19	0.01559^{B}±0.80	133.73
	F-value	2866.5	148.5	45.49	145.27	784.26	169.81	-
	P- value	0.000	0.000	0.000	0.000	0.000	0.000	-

Different letters refer to significant results at $p<0.05$, while the same letters refer to insignificant results at $p>0.05$ using One- way ANOVA.

Table 4: Spatial variations of heavy metals content determined in insects' samples collected from different sites in the 10th Ramadan District, Egypt (2021-2022).

Insects (Studied areas)	Fe (mg/g)	Zn (mg/g)	Cu (mg/g)	Pb (mg/g)	Cd (mg/g)	Mn (mg/g)	Sum (mg/g)
Control (*Alphitobius* sp.)	2628^{a}±1.7	336.3^{a}±2.5	54.67^{a}±4.5	0.0413^{a}±3.2	0.4910^{a}±12.8	0.0762^{a}± 1.8	3019.58
Heavy (*Alphitobius* sp.)	6778.7^{b}±1.5	277.4^{b}±2.5	81.8^{b}±3	0.0757^{b}±3.1	0.32310^{b}±21.2	0.0932^{b}±1.9	71238.39
Medium (*Alphitobius* sp.)	1928^{c}±1.7	232.9^{c}±2.6	123.9^{c}±4	0.0124^{c}±0.5	0.07193^{c}±3.2	0.0484^{c}±1.9	2284.93
Light (*Alphitobius* sp.)	8337.5^{d}±2.5	286.8^{d}±2	3274.3^{d}±4.5	0.0225^{d}±0.6	0.29527^{b}±5.8	0.1068^{d}±3	11898.02
F-value	8193395.96	921.53	462229.46	459.46	541.02	337.67	-
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Control (*Zophosis* sp.)	224.5^{a}±1.5	202.5^{a}±2.5	17.97^{a}±1	0.0089^{a}±0.13	0.02353^{a}±3.5	0.0250^{ac}±2	445.03
Heavy (*Zophosis* sp.)	796.5^{b}±2.5	247.8^{b}±2.6	22.3^{ab}±2.5	0.00512^{b}±0.1	0.02567^{a}±0.8	0.03091^{b}±2	1066.66
Medium (*Zophosis* sp.)	294.5^{c}±1.3	253.5^{b}±3.5	27.03^{b}±2	0.0074^{c}±.036	0.0330^{b}±2.1	0.02875^{bc}±2	575.10
Light (*Zophosis* sp.)	NF	NF	NF	NF	NF	NF	-
F-value	85454.766	280.646	16.268	206.824	12.965	6.594	-
P-value	<0.001	<0.001	0.004	<0.001	0.007	0.031	-
Control (*Pangaeus* sp.)	241.5^{a}±3.1	55.4^{a}±3.5	51.1^{a}±2	0.0028^{a}±0.25	0.00709^{a}±0.8	0.02406^{a}±2	321.03
Heavy (*Pangaeus* sp.)	13053.8^{b}±4.7	235.3^{b}±3.4	134.7^{b}±4.5	0.0857^{b}±1.2	0.5313^{b}±6.1	0.10217^{b}±2	13424.52
Medium (*Pangaeus* sp.)	8744.4^{c}±5.1	1001.9^{c}±2	167.8^{c}±2.5	0.0284^{c}±0.5	0.1828^{c}±3.6	0.12089^{c}±1.7	9914.03
Light (*Pangaeus* sp.)	NF	NF	NF	NF	NF	NF	-
F-value	6745302.59	79383.01	1056.64	9776.82	12538.78	2198.54	-
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-
Control (*Cataglyphis* sp.)	217.87^{a}±2.6	332.73^{a}±3	94.6^{a}±4	0.00108^{a}±0.1	0.2265^{a}±9.2	0.25607^{a}±4	645.68
Heavy (*Cataglyphis* sp.)	300.0^{b}±3	32.6^{b}±2.5	56.2^{b}±3	0.00183^{a}±0.5	0.3199^{b}±19.6	0.13734^{b}±2.5	389.26
Medium (*Cataglyphis* sp.)	645.2^{c}±5	211.93^{c}±4	28.9^{c}±1.7	0.0035^{a}±0.5	0.3517^{b}±48.1	0.08485^{c}±3	886.47
Light (*Cataglyphis* sp.)	1215.4^{d}±4.5	263.4^{d}±3.5	372.2^{d}±3	0.0666^{b}±3.5	0.08597^{c}±4.9	0.06101^{d}±3	1851.21
F-value	40426.12	4513.86	7893.36	974.83	60.74	2242.45	-
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-

NF: refers to the types of insects that were not found in this region. Different letters refer to significant results at *$p<0.05$*, while the same letters refer to insignificant results at *$p>0.05$* using One- way ANOVA

Table 5: Spatial variation of pollution indices in different species in the 10th Ramadan District, Egypt (2021-2022)

Insect species	pollution index	Heavy industries	Medium industries	Light industries
Alphitobius sp.	**Efs**	0.468± 0.19	1.102± 1.15	3.990±8.32
	BSAF	32.89±35.8	19.95±18.1	445.73±1006.5
	MPI	8.397	3.659	13.31
Zophosis sp.	**Efs**	0.303±0.08	0.936±0.20	NF
	BSAF	8.33±10.5	6.74±4.8	NF
	MPI	1.62	1.56	NF
Pangaeus bilinatus	**Efs**	0.434±0.58	0.344±0.26	NF
	BSAF	53.68±72.1	57.59±60.6	NF
	MPI	11.19	9.87	NF
Cataglyphis sp.	**Efs**	0.629±0.48	0.409±0.42	2.402±4.84
	BSAF	26.14±38.8	28.51±42.0	64.64±108.7
	MPI	3.16	3.27	5.89

Pollution indices symbols are BAF, bioaccumulation factor; EFs, heavy metal enrichment factors; and MPI, metal pollution index.

4. Discussion

The main objective of the current work is to investigate the level of heavy metal contamination in different sites of 10th of Ramadan City by using insects and plants as bioindicators in addition to soil contamination. Around the world, biomonitoring and bioassessment programs heavily depend on insects, which are usually the most prevalent category of invertebrate fauna [87]. Fifteen different insect species were found during the time of this investigation. These species have belonged to seven distinct families which belong to five orders. Among the recognized families the most abundant families were Formicidae and Tenebrionidae and this is agreeable to the results of Taraslia et al. [79] in Cyprus, who found that the most abundant orders were Coleoptera and ants while the most dominant family of Coleoptera was Tenebrionidae. The spatial variance of species diversity at the control sites and three groups of industrial levels: light, medium, and heavy sites were represented. Heavy industrial sites showed the highest value of species richness. This result may be due to the high presence of coleopteran and hymenopteran insects as they showed a high species richness even with pollutants from the industry. Meanwhile, hemipteran species richness was low in industrial regions according to Jana et al. [36], who demonstrated that the non-industrial zone has a higher species richness of Hemiptera than the industrial zone. Light industrial sites showed the maximal value of diversity index and minimum value of dominance index as these sites contain no hemipteran insects and this was matched with the results of Jana et al. [35], who estimated that the diversity values of Hemiptera in the industrial area show a gradual decrease compared to nonindustrial study sites, while other study sites showed approximately similar diversity values for Coleoptera and Hymenoptera. Also, the evenness index showed its minimum value in heavy industrial sites because one species (Hymenoptera) has become overly dominant.

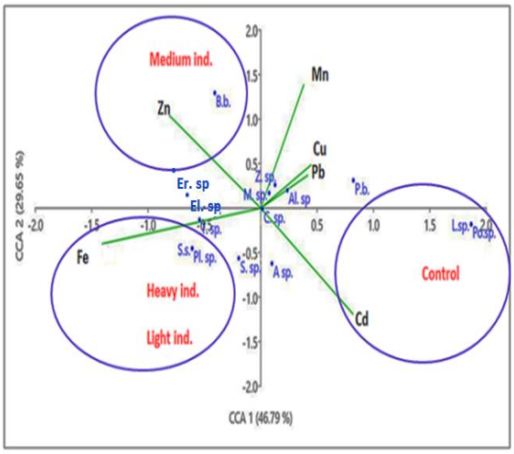

Figure 4: Ordination diagram of Canonical Corresponding Analysis (CCA) showed the correlation between insect species and heavy metals at different study areas.

Other sites had higher values due to the presence of most species, which were distributed in approximately equal numbers, this was compatible with Singh et al. [74].

The seasonal variations had significant effects on the diversity parameters of the terrestrial insect community in the current study. Similar results were observed in earlier research in different ecosystems and Mediterranean regions [69, 1, 23, 53, 57]. The highly significant number of dominant families found in the spring and autumn may be connected to the mild climate conditions that have a good effect on terrestrial arthropod phenology. On the other hand, the summer months' decrease in herbivorous arthropods (like Hemiptera) could be attributed to the lack of food during this hot and dry season [3].

In our result also, spring had the highest species richness value. However, winter has the lowest number of insects and abundance due to unsuitable climatic factors and short-day time. Meanwhile, during the autumn, there was a noticeable rise in the species' abundance linked to an increase in the number of ant individuals. Autumnal decreases in species diversity and species evenness of community correlated with increases in community abundance associated with specific species, which is compatible with Bream et al. [11], who found the same results in the Menoufia governorate.

Soil is believed to be one of the most effective tracers for tracking the effects of human activities, particularly industrial emissions. As well as, plants that directly absorb heavy metals from the soil and their surroundings through their roots, stems, or shoots [17, 59, 54, 76]. El-Khatib et al. [20] demonstrated the applicability of using tree leaves of *F. macrocarpa* as biomonitors to measure metal levels in the air in the current study, we studied the levels of heavy metals in soil and plants. It was found that the heavy metals were found to accumulate in the following order Fe >Mn>Zn>Cd>Pb>Cu from large to small amounts in the examined soil samples. These results are partially consistent with Guo et al. [27], who ordered mean concentrations of the heavy metals in the urban soils of southwest China as follows Zn > Pb > Cu. Meanwhile, heavy metals accumulation in leaves of *F. macrocarpa* was as follows Fe>Cd>Mn>Zn>Cu>Pb.

The present results showed that the highest value of heavy metals was in light industries sites, which were incompatible with Bream *et al*. [11] and this may be due to the high number of small factories in small areas. Our results showed that heavy industry sites have the highest value of Cu and Pb due to factory manufacturing cables made of copper wiring, and a metal processing factory according to Moon et al. [60] name of author found similar results. Iron (Fe) was the highest metal in concentration, because it comprises particle materials, stabilizes trace metals by complexion, and is distinguished by its surfactant and correlation qualities as various authors have stated [73,28]. However, the concentration of Mn found in this study increased, followed by iron. This could be related to the rise of various heavy and medium industries, as well as the release of domestic and industrial waste as indicated by Rani and Reddy [72], Khaled [41], and Osman [64], who established the presence of this element due to domestic and industrial waste. Finally, the concentration of heavy metals was higher in the plant than in the soil, especially for Fe and Cd, this agrees with the finding of Khan et al. [43] in the soil that *Withania somnifera* was grown in and in the plant itself.

The present investigation examined the build-up of heavy metals in terrestrial insects: *Cataglyphis* sp., *Zophosis* sp., *Alphitobius* sp., and *Pangaeus bilineatus.* In the current study, the whole body of insects was used to detect the heavy metals. It is more accurate than each organ of insects and better since it represents the higher concentration of heavy metals as investigated by Cain et al. [12]. Our investigation showed that terrestrial insects showed patterns of site-specific metal accumulation.

This may be due to greater exposure to toxic elements [11, 70, 48]. In the present work, light industrial sites recorded the highest level of heavy metals, and these results are compatible with high levels of heavy metals in soil and plants in this area according to findings of Jelaska et al. [37], who found a correlation between the level of metals in soil and in insects. Also, samples of the heavy industry sites contain high levels of (Fe), (Zn), (Mn), and (Cu) where heavy industries like those in metallurgy, marble, engineering, and electrical products are concentrated. These industries serve as a good explanation for the rise in heavy industrial sites and lessen this metal build-up by extending the distance from distant sources of pollution. Also, this finding concurs with Heliövaara and Väisänen [29], who observed that the European pine sawfly's metal levels decreased steadily with increasing distance from industrial sites in the adult, immature and larval stages.

Table 6: Canonical Corresponding Analysis (CCA) axes, Eigenvalue, Variance %, and Cumulative %

Codes	Variables	CCA 1	CCA 2	CAA 3
M. sp.	*Myermeleon* sp. (nymph)	0.074	0.170	0.464
P.b.	*Pangaeus bilinatus*	0.822	0.312	0.117
T. sp.	*Tentyrina* sp.	-0.543	-0.132	-0.152
Z. sp.	*Zophosis* sp.	0.127	0.262	0.389
E sp.	*Eleodes* sp	-0.525	0.091	-0.053
A sp.	*Attagenus* sp.	0.099	-0.623	-0.355
S. sp.	*Spilostethus* sp.	-0.195	-0.563	0.191
E. sp.	*Erodius* sp.	-0.471	0.362	-1.020
B.b.	*Bimelia bipuncutate*	-0.408	1.294	-0.065
S.s.	*Scaurus striatus*	-0.609	-0.453	1.085
L.sp.	*Lapidura* sp.	1.867	-0.181	0.061
Po.sp.	*Poecilus* sp.	1.870	-0.181	0.061
Al. sp	*Alphitobius* sp.	0.235	0.200	-0.208
Pl. sp.	*Plaps* sp.	-0.609	-0.453	1.085
C. sp.	*Cataglyphis* sp.	0.015	-0.009	-0.149
Sites	Control	1.870	-0.180	0.052
	Heavy ind.	-0.616	-0.455	1.103
	Medium ind.	-0.352	1.767	-0.382
	Light ind.	-0.582	-1.040	-1.682
Fe	Iron	-0.937	-0.267	-0.376
Zn	Zinc	-0.609	0.781	-0.167
Cu	Copper	0.297	0.322	0.968
Pb	Lead	0.277	0.244	0.984
Cd	Cadmium	0.545	-0.793	0.262
Mn	Manganese	0.254	0.921	0.442
Eigenvalue		0.24	0.15	0.12
Variance %		46.8	29.7	23.6
Cumulative %		46.8	76.4	100

The current study showed various insect species with significant variations in levels of heavy metals and this is compatible with Mwelwa et al. [61], who found a substantial difference in the daily intake of various insect species. Also, the current results showed that insects from order: Hemiptera such as (*Pangaeus bilinatus*) can accumulate more heavy metals than others, and that agrees with Heliövaara et al. [30], who found that insects from order: Hemiptera can accumulate high levels of heavy metals due to their lifestyle and feeding characteristics.

The enrichment factors (EFs) at different industrial sites were calculated, and the highest values of enrichment factors were observed in light industry sites, which lay between the moderate range (2< EF <5) according to Barbieri [5]. Other industry sites showed low values of enrichment factors and indicated that the detected metals didn't exceed the natural level. The variation in EF values could be brought about by variations in the amount of metal intake for the sediment and/or variations in the rate at which metals are removed from the sediment. The chemical form and quantity of every trace metal in sediments determines its bioavailability and toxicity [47]. Conversely, the bioaccumulation factor of sediment (BAF) was calculated for the different sites, and the highest value was found at light industry sites and declined in heavy and medium industry sites. High BAF suggested that the examined insects have a probability of accumulating heavy metals in their bodies similar to the finding of [78, 16, 56]. Additionally, in our results, the highest value of (MPI) was recorded at light industry sites which confirmed the results of (EFs) and (BAF), which indicated that the highest polluted sites were those of light industry compared to other industry sites and this may be reasonable because light industry sites contain large numbers of factories (chocolate machinery factories, packaging and wrapping factories, deep freezer factories, textile ink factories, and some food industry) in a small area. This result is similar to the conclusion of Khaled et al. [42], who found that high MPI values indicated high pollution.

5. Conclusion

The present study highlights the dangers of metal pollution to living organisms and the surrounding ecosystem. Using successful tools such as biodiversity indices and pollution indices is important in recording levels of heavy metals (Mn, Zn, Cu, Fe, and Pb) in the industrial area of the 10th Ramadan District, Egypt. It also brings forward the scope of different insects to be used as a tool to study environment quality and conditions. This through some lights on metal pollution as one of the most dangerous pollutions.

Recommendations.

Consequently, the report recommends that appropriate steps to be taken to reduce the growing levels of pollution:

1. regulating the proper disposal of industrial effluents in industrial sites and rigorously enforcing such rules.
2. increasing the Green GDP
3. implementing more renewable energies and adopting market-based approaches.
4. it is necessary to coordinate the activities of the governments and markets to control the discharges of heavy metals

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