International Journal of Theoretical and Applied Research, 2025, Vol. 4, No. 1, 525-538

International Journal of Theoretical and Applied Research (IJTAR)
ISSN: 2812-5878

Homepage: https://ijtar.journals.ekb.eg

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)

Toqa M. Rashed[1*], Saber A. Riad[1], Manal E.A. Elshaier [1], Moselhy W.A[1], Sara S. M. Sayed[2]

[1]*Zoology Department, Faculty of science, Al Azhar University, Nasr city, Cairo, Egypt.*
[2]*Environmental Research Department, Theodor Bilharz Research Institute, Giza, Egypt*

ARTICLE INFO

Received 17/12/2024
Revised 05/01/2025
Accepted 19/02/2025

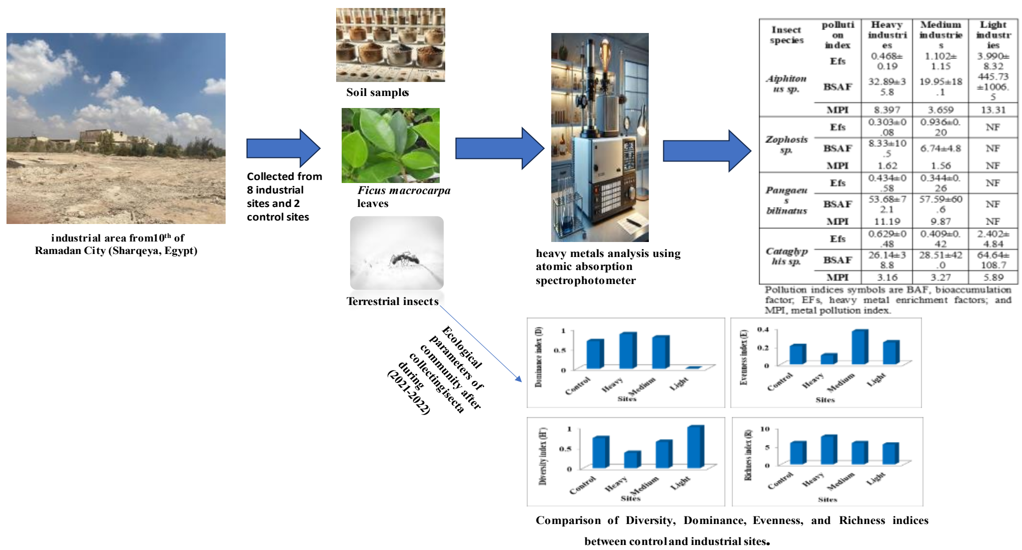
Keywords

Bioindicators
Canonical correspondence analysis
Pollutants
Dominance index
Diversity index

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



⁎ *Corresponding author*
E-mail address: toqa.rashed123@gmail.com

DOI: **10.21608/IJTAR.2025.345376.1100**

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].

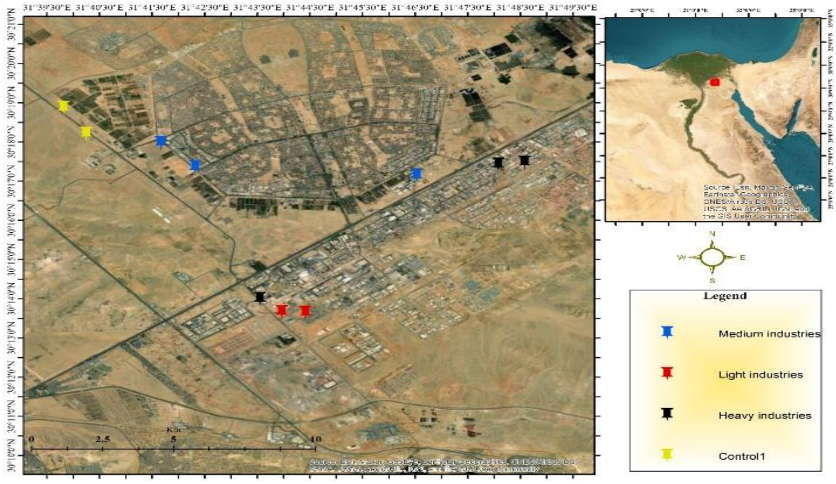


Figure 1: Map of the geographical location of the study area and sampling sites in 10th of Ramadan city, Sharqeya governorate, Egypt.

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

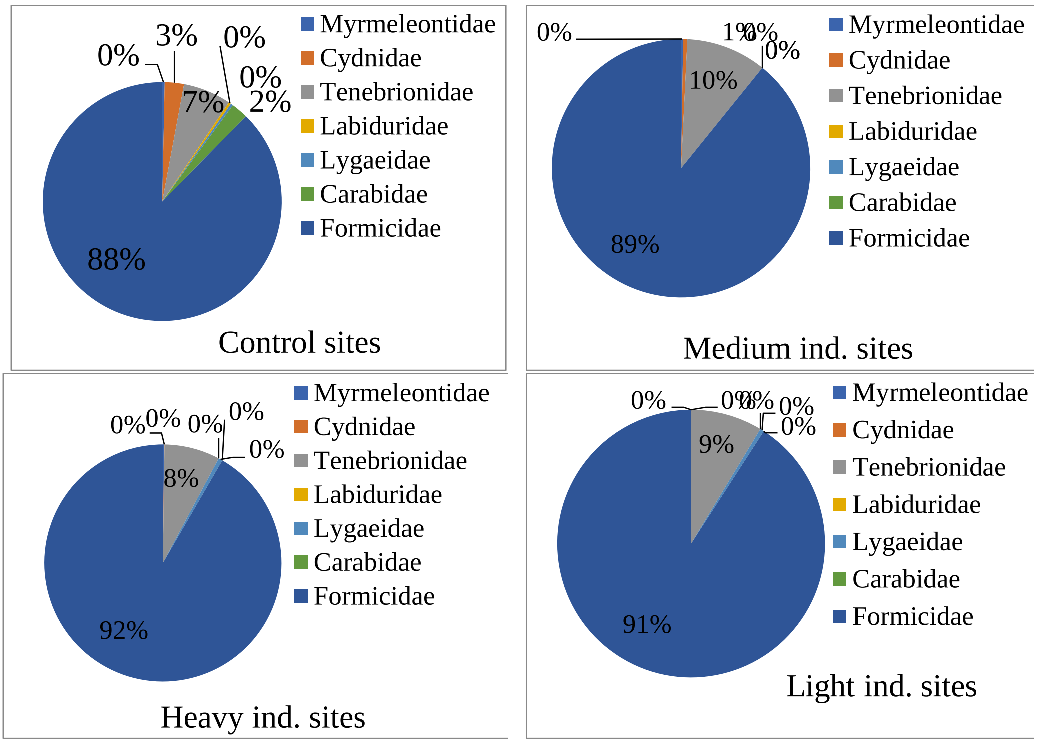


Figure 2: Percentage proportion of insect families sampled from the control and different industrial sites in the 10th Ramadan District, Egypt (2021-2022).

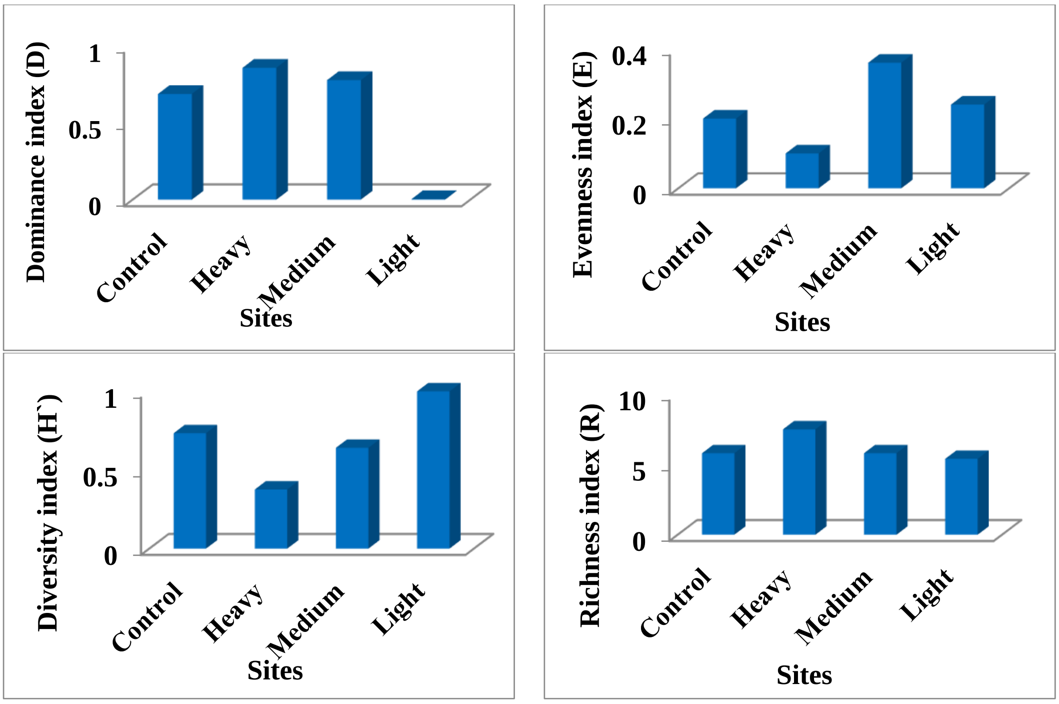


Figure 3: Comparison of Diversity, Dominance, Evenness, and Richness indices between control and industrial sites.

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, $0.5 < D \leq 0.75$ = Moderate Dominance, $0.75 < D \leq 1.0$ = High Dominance).
- Diversity index was ($H` \leq 1$ = Low diversity, $1 < H` \leq 3$ = Moderate diversity, $H` \geq 3$ = high diversity).
- Evenness index was ($0 < E \leq 0.5$ = Depressed community, $0.5 < E \leq 0.75$ = Unstable community, $0.75 < E \leq 1$ = 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.

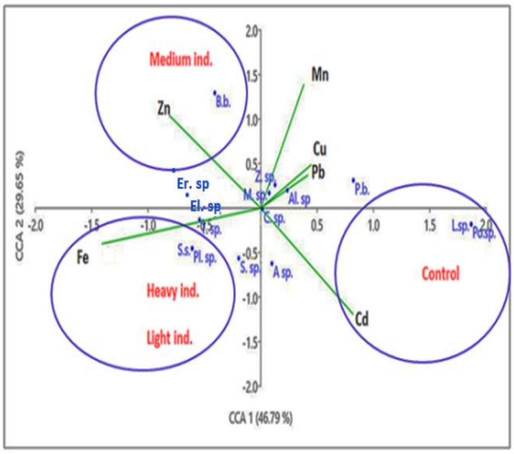


Figure 4: Ordination diagram of Canonical Corresponding Analysis (CCA) showed the correlation between insect species and heavy metals at different study areas.

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.

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

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.

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

Acknowledgement

The authors express profound thanks to Dr. Wafaa A. Mohammed for her help in determining heavy metals in the collected samples.

References

1. Abd El-Wakeil KF, Mahmoud HM, Hassan MM. Spatial and seasonal heterogeneity of soil macroinvertebrate community in Wadi Al-Arj, Taif, Saudi Arabia. Jökull Journal. 2014;64(4):180-201.
2. Abrahim GM, Parker RJ. Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environmental monitoring and assessment. 2008 Jan;136(1):227-38. https://doi.org/10.1007/s10661-007-9678-2
3. Ajerrar A, Zaafrani M, Qessaoui R, Aabd NA, Bahadou H, Lahmyed H, Furze JN, Chebli B, Bouharroud R. Terrestrial arthropods diversity in the Argan Biosphere Reserve: Seasonal dynamics and ecological function roles. Journal of the Saudi Society of Agricultural Sciences. 2023 Jan 1;22(1):1-0. https://doi.org/10.1016/j.jssas.2022.05.003
4. Alkan F, Koksal M, Ergun D, Karis D, Ozsobaci N, Barutcu U. ELEMENT INTOXICATION BY MARINE FOOD. Med Sci Discov. 2015;2(2):176-81.
5. Barbieri M. The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. Journal of Geology & Geophysics. 2016;5(1):1-4. https://hdl.handle.net/11573/925249
6. Bednarska AJ, Stachowicz I, Kuriańska L. Energy reserves and accumulation of metals in the ground beetle Pterostichus oblongopunctatus from two metal-polluted gradients. Environmental Science and Pollution Research. 2013 Jan; 20:390-8. https://doi.org/10.1007/s11356-012-0993-y
7. Belskii E, Belskaya E. Diet composition as a cause of different contaminant exposure in two sympatric passerines in the Middle Urals, Russia. Ecotoxicology and environmental safety. 2013 Nov 1; 97:67-72. https://doi.org/10.1016/j.ecoenv.2013.07.014
8. Białońska D, Dayan FE. Chemistry of the lichen Hypogymnia physodes transplanted to an industrial region. Journal of Chemical Ecology. 2005 Dec; 31:2975-91. https://doi.org/10.1007/s10886-005-8408-x
9. Biggs EM, Herrmann A, Cognato AI. Dichotomous key to adults of economically important dermestids (Coleoptera: Dermestidae) of Canada and the United States. Canadian Journal of Arthropod Identification. 2022 Feb 1(46).
10. Boulos L. Flora of Egypt. Azollaceae–Oxalidaceae. Vol. I. Cairo: Al-Hadara Publ.; 1999. p. 419.
11. Bream AS, El Surtasi EI, Mahmoud MA, Hamza YI. Industrial Pollution Evaluation through Enzymatic Biomarkers at Different Localities of El-

Sadat Industrial City, Menofia, Egypt. Egyptian Academic Journal of Biological Sciences. A, Entomology. 2019 Jun1;12(3):19-36. DOI: 10.21608/eajbsa.2019.31189

12. Cain DJ, Luoma SN, Axtmann EV. Influence of gut content in immature aquatic insects on assessments of environmental metal contamination. Canadian Journal of Fisheries and Aquatic Sciences. 1995 Dec 1;52(12):2736-46. https://doi.org/10.1139/f95-862
13. Carter MR, Gregorich EG. Soil sampling and methods of analysis. CRC press; 2007 Aug 3. https://doi.org/10.1201/9781420005271
14. Watt JC. Tenebrionidae (Insecta: Coleoptera): catalogue of types and keys to taxa. Fauna of New Zealand. 1992 Jul 13;26. https://doi.org/10.7931/J2/FNZ.26
15. Choate PM. Ground Beetle (Coleoptera: Carabidae) Taxonomy. Encyclopedia of Entomology (Editedby John L. Capinera, 2nd edition). 2008; 2:1747-52.
16. Conti E, Dattilo S, Costa G, Puglisi C. The ground beetle Parallelomorphus laevigatus is a potential indicator of trace metal contamination on the eastern coast of Sicily. Ecotoxicology and environmental safety. 2017 Jan 1; 135:183-90. https://doi.org/10.1016/j.ecoenv.2016.09.029
17. Dahmani-Muller H, Van Oort F, Gélie B, Balabane M. Strategies of heavy metal uptake by three plant species growing near a metal smelter. Environmental pollution. 2000 Aug1;109(2):231-8. https://doi.org/10.1016/S0269-7491(99)00262-6
18. Danesino C. Environmental indicators for heavy metals pollution: soils and higher plants. Sci Acta. 2009; 3:23-6.
19. Echols K, Meadows J, Orazio C. Pollution of aquatic ecosystems II: hydrocarbons, synthetic organics, radionuclides, heavy metals, acids, and thermal pollution.2009; 120-128.
20. El-Khatib AA, Barakat NA, Youssef NA, Samir NA. Bioaccumulation of heavy metals air pollutants by urban trees. Int J Phytoremediation.2020;22(2):210-22. https://doi.org/10.1080/15226514.2019.1652883 .
21. Estefan G, Sommer R, Ryan J. Methods of soil, plant, and water analysis. A manual for the West Asia and North Africa region. 2013;3(2013):65-119. https://hdl.handle.net/20.500.11766/7512
22. European Environment Agency. Heavy metal (HM) emissions (APE 005). Copenhagen: European Environment Agency; 2011.
23. Farina A. Application of landscape and soundscape ecology to the Mediterranean region. Journal of Mediterranean Ecology. 2015; 13:21-7.
24. Finnamore AT. The advantages of using arthropods in ecosystem management. Biological Survey of Canada (Terrestrial Arthropods) for Canadian Museum of Nature and Entomological Society of Canada, Ottawa. 1996.
25. Garbisu C, Alkorta I. Basic concepts on heavy metal soil bioremediation. ejmp & ep (European Journal of Mineral Processing and Environmental Protection). 2003 Jan 1;3(1):58-66.
26. Gbarato Oliver L, Okujagu DC, Okujagu CU. Detection of the presence of heavy metal pollutants in Eleme Industrial Area of Rivers State, Nigeria. The International Journal Of Engineering And Science (IJES). 2015;4(9):54-8.
27. Guo G, Wu F, Xie F, Zhang R. Spatial distribution and pollution assessment of heavy metals in urban soils from southwest China. Journal of environmental sciences. 2012 Mar 1;24(3):410-8. https://doi.org/10.1016/S1001-0742(11)60762-6
28. Harrison RM, De Mora SJ. Introductory chemistry for the environmental sciences. Cambridge University Press; 1996 Jun 6.
29. Heliövaara K, Väisänen R. Concentrations of heavy metals in the food, faeces, adults, and empty cocoons of Neodiprion sertifer (Hymenoptera, Diprionidae) *Bull Environ Contam Toxicol*. 1990;45(1):13-8. DOI: **10.1007/BF01701822**
30. Heliövaara K, Väisänen R, Braunschweiler H, Lodenius M. Heavy metal levels in two biennial pine insects with sap-sucking and gall-forming lifestyles. Environmental pollution. 1987 Jan 1;48(1):13-23. https://doi.org/10.1016/0269-7491(87)90082-0
31. Goulet H, Huber JT, editors. Hymenoptera of the world: an identification guide to families. 1993.
32. Hussein EE, Fouad M, Gad MI. Prediction of the pollutant's movements from the polluted industrial zone in 10th of Ramadan city to the Quaternary aquifer. Applied water science. 2019 Feb;9(1):20. https://doi.org/10.1007/s13201-019-0897-9
33. Capinera JL, editor. Insect Keys. In: Encyclopedia of Entomology. Dordrecht: Springer; 2008. Available from: https://doi.org/10.1007/978-1-4020-6359-6_1487
34. Ives AR, Cardinale BJ. Food-web interactions govern the resistance of communities after non-random extinctions. Nature. 2004 May 13;429(6988):174-7. https://doi.org/10.1038/nature02515
35. Jana G, Chaki KK, Misra KK. Quantitative estimation of insect diversity inhabiting Calotropis procera in industrial and nonindustrial areas of West Bengal, India. Ecological research. 2012 Jan; 27:153-62. https://doi.org/10.1007/s11284-011-0883-7
36. Jana G, Misra KK, Bhattacharya T. Diversity of some insect fauna in industrial and non-industrial areas of West Bengal, India. Journal of insect conservation. 2006 Sep; 10:249-60. https://doi.org/10.1007/s10841-005-5094-5
37. Jelaska LŠ, Blanuša M, Durbešić P, Jelaska SD. Heavy metal concentrations in ground beetles, leaf litter, and soil of a forest ecosystem. Ecotoxicology and Environmental Safety. 2007 Jan 1;66(1):74-81.https://doi.org/10.1016/j.ecoenv.2005.10.017

38. John AO, Sylvester AA, Kehinde AO, Michael AA. Land Use Impacts on Diversity and Abundance of Insect Species. In Vegetation Dynamics, Changing Ecosystems and Human Responsibility 2022 Oct 10. Intech Open.
39. Jones ME, Paine TD. Detecting changes in insect herbivore communities along a pollution gradient. Environmental Pollution. 2006 Oct 1;143(3):377-87. https://doi.org/10.1016/j.envpol.2005.12.013
40. Karavin M. Metal bioaccumulation in some Auchenorrhyncha (Hemiptera) species in apple orchards. International Journal of Agriculture Environment and Food Sciences. 2024 Jun 6;8(2):369-77. https://doi.org/10.31015/jaefs.2024.2.12
41. Khaled A. Heavy metals concentrations in certain tissues of five commercially important fishes from El-Mex Bay, Alexandria, Egypt. Egypt J Aquatic Res (2004).
42. Khaled A, El Nemr A, El Sikaily A. An assessment of heavy-metal contamination in surface sediments of the Suez Gulf using geoaccumulation indexes and statistical analysis. Chemistry and Ecology. 2006 Jun 1;22(3):239-52. https://doi.org/10.1080/02757540600658765
43. Khan MA, Ahmad I, Rahman IU. Effect of environmental pollution on heavy metals content of Withania somnifera. Journal of the Chinese Chemical Society. 2007 Apr;54(2):339-43. **https://doi.org/10.1002/jccs.200700049**
44. King JR, Porter SD. Evaluation of sampling methods and species richness estimators for ants in upland ecosystems in Florida. Environmental Entomology. 2005 Dec 1;34(6):1566-78. https://doi.org/10.1603/0046-225X-34.6.1566
45. Koz B, Çevik U, Akbulut SO. Heavy metal analysis around Murgul (Artvin) copper mining area of Turkey using moss and soil. Ecological Indicators. 2012 Sep 1; 20:17-23. https://doi.org/10.1016/j.ecolind.2012.02.002
46. Kumar T, Tripathi G. Impact of Industrial Pollution on Soil Faunal Biodiversity: A Case Study Around Jodhpur City. Journal 0f Experimental Zoology India. 2019 Jan 1;22(1).
47. Kwon YT, Lee CW, Ahn BY. Sedimentation pattern and sediments bioavailability in a wastewater discharging area by sequential metal analysis. Microchemical Journal. 2001 Mar 1;68(2-3):135-41. https://doi.org/10.1016/S0026-265X(00)00140-5
48. Lagisz M, Kramarz P, Niklinska M. Metal Kinetics and Respiration Rates in F 1 Generation of Carabid Beetles (Pterostichus oblongopunctatus F.) Originating from Metal-Contaminated and Reference Areas. Archives of Environmental Contamination and Toxicology. 2005 May; 48:484-9. https://doi.org/10.1007/s00244-004-0023-2
49. Lau S, Mohamed M, Yen AT, Su'Ut S. Accumulation of heavy metals in freshwater molluscs. Science of the total environment. 1998 Jun 18;214(1-3):113-21. https://doi.org/10.1016/S0048-9697(98)00058-8
50. Breitkreuz LC, Garzón-Orduña IJ, Winterton SL, Engel MS. Phylogeny of Chrysopidae (Neuroptera), with emphasis on morphological trait evolution. Zoological Journal of the Linnean Society. 2022 Apr 1;194(4):1374-95. https://doi.org/10.1093/zoolinnean/zlab024
51. Lemieux JP, Lindgren BS. A pitfall trap for large-scale trapping of Carabidae: comparison against conventional design, using two different preservatives. (1999): 245-253.
52. Lindsey PA, Skinner JD. Ant composition and activity patterns as determined by pitfall trapping and other methods in three habitats in the semi-arid Karoo. Journal of Arid Environments. 2001 Aug 1;48(4):551-68. *https://doi.org/10.1006/jare.2000.0764*
53. Liu R, Steinberger Y. Seasonal distribution and diversity of ground-active arthropods between shrub microhabitats in the Negev Desert, Israel. Arid Land Research and Management. 2018 Jan 2;32(1):91-110. https://doi.org/10.1080/15324982.2017.1389774
54. Lu A, Wang J, Qin X, Wang K, Han P, Zhang S. Multivariate and geostatistical analyses of the spatial distribution and origin of heavy metals in the agricultural soils in Shunyi, Beijing, China. Science of the total environment. 2012 May 15; 425:66-74. https://doi.org/10.1016/j.scitotenv.2012.03.003
55. Lu SG, Bai SQ, Xue QF. Magnetic properties as indicators of heavy metals pollution in urban topsoil: a case study from the city of Luoyang, China. Geophysical Journal International. 2007 Nov 1;171(2):568-80. https://doi.org/10.1111/j.1365-246X.2007.03545
56. Mahmoud MA. *Ecological and Biochemical studies on some aquatic insects, from certain water streams, as biomonitors for heavy metal pollution in different localities, Egypt* (Doctoral dissertation, Ph. D. Thesis, Zoo & Ent. Dept. Fac. Of Science, Al Azhar Univ., Egypt, Retrieved from https://www. researchgate. net).
57. Majeed W, Rana N, de Azevedo Koch EB, Nargis S. Seasonality and climatic factors affect diversity and distribution of arthropods around wetlands. Pakistan Journal of Zoology. 2020 Dec 1;52(6):2135-44.
58. Margalef R. Information theory in ecology. *Gen Syst*. 1958; 3:36-71.
59. Monni S, Uhlig C, Hansen E, Magel E. Ecophysiological responses of Empetrum nigrum to heavy metal pollution. Environmental Pollution. 2001 Apr 1;112(2):121-9. https://doi.org/10.1016/S0269-7491(00)00125-1
60. Moon CH, Lee YS, Yoon TH. Seasonal variation of heavy metal contamination of topsoils in the Taejun-industrial complex (II). Environmental technology. 1991 May 1;12(5):413-9. https://doi.org/10.1080/09593339109385025
61. Mwelwa S, Chungu D, Tailoka F, Beesigamukama D, Tanga C. Biotransfer of heavy metals along the

soil-plant-edible insect-human food chain in Africa. Science of the Total Environment. 2023 Jul 10; 881:163150. https://doi.org/10.1016/j.scitotenv.2023.163150

62. Ndimele PE, Pedro MO, Agboola JI, Chukwuka KS, Ekwu AO. Heavy metal accumulation in organs of Oreochromis niloticus (Linnaeus, 1758) from industrial effluent-polluted aquatic ecosystem in Lagos, Nigeria. Environmental monitoring and assessment. 2017 Jun; 189:1-5. https://doi.org/10.1007/s10661-017-5944-0
63. Opaluwa OD, Aremu MO, Ogbo LO, Abiola KA, Odiba IE, Abubakar MM, Nweze NO. Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. Advances in Applied Science Research. 2012 Nov 7;3(2):780-4.
64. Osman AG. Biomarkers in Nile tilapia Oreochromis niloticus niloticus (Linnaeus, 1758) to assess the impacts of river Nile pollution: bioaccumulation, biochemical and tissues biomarkers. Journal of Environmental Protection. 2012 Aug 21;3(8):966-77. **DOI:** 10.4236/jep.2012.328112
65. Osman W, M. El-Samad L, Mokhamer EH, El-Touhamy A, Shonouda M. Ecological, morphological, and histological studies on Blaps polycresta (Coleoptera: Tenebrionidae) as biomonitors of cadmium soil pollution. Environmental Science and Pollution Research. 2015 Sep; 22:14104-15. https://doi.org/10.1007/s11356-015-4606-4
66. Parikh G, Rawtani D, Khatri N. Insects as an indicator for environmental pollution. Environmental Claims Journal. 2021 Mar 30;33(2):161-81. https://doi.org/10.1080/10406026.2020.1780698
67. Peet RK. The measurement of species diversity. Annual review of ecology and systematics. 1974 Jan 1:285-307. https://www.jstor.org/stable/2096890
68. Pielou EC. The measurement of diversity in different types of biological collections. Journal of theoretical biology. 1966 Dec 1; 13:131-44. https://doi.org/10.1016/0022-5193(66)90013-0
69. Piñero FS, Tinaut A, Aguirre-Segura A, Miñano J, Lencina JL, Ortiz-Sánchez FJ, Pérez-López FJ. Terrestrial arthropod fauna of arid areas of SE Spain: Diversity, biogeography, and conservation. Journal of Arid Environments. 2011 Dec 1;75(12):1321-32. https://doi.org/10.1016/j.jaridenv.2011.06.014
70. Purchart L, Kula E, Suchomel J. The reaction of ground beetle (Coleoptera: Carabidae) assemblages to a contaminated mining site in Central Europe. Community Ecol. 2010; 11:242-9.
71. Quevauviller P, Imbert JL, Ollé M. Evaluation of the use of microwave oven systems for the digestion of environmental samples. Microchimica Acta. 1993 Jan; 112:147-54. https://doi.org/10.1007/BF01243331
72. Rani PS, Reddy PM. Preliminary studies on metal concentration on Hussain Sagar Lake. Pollution Research. 2003;22(3):377-80.
73. Rashid MA, Leonard JD. Modifications in the solubility and precipitation behavior of various metals as a result of their interaction with sedimentary humic acid. Chemical Geology. 1973 Apr 1;11(2):89-97. https://doi.org/10.1016/0009-2541(73)90045-4
74. Singh K, Thind J, Thukral K, Singh A, Singh R. BIODIVERSITY AND SEASONAL ABUNDANCE OF INSECTS IN SUGARCANE CROP IN AMRITSAR REGION OF NORTH INDIA. Annals of Entomology. 2023 Jan 1;41(1).
75. Skaldina O, Peräniemi S, Sorvari J. Ants and their nests as indicators for industrial heavy metal contamination. Environmental Pollution. 2018 Sep 1; 240:574-81. https://doi.org/10.1016/j.envpol.2018.04.134
76. Soriano A, Pallarés S, Pardo F, Vicente AB, Sanfeliu T, Bech J. Deposition of heavy metals from particulate settleable matter in soils of an industrialised area. Journal of Geochemical Exploration. 2012 Feb 1; 113:36-44. https://doi.org/10.1016/j.gexplo.2011.03.006
77. Szefer P, Ali AA, Ba-Haroon AA, Rajeh AA, Gełdon J, Nabrzyski M. Distribution and relationships of selected trace metals in molluscs and associated sediments from the Gulf of Aden, Yemen. Environmental Pollution. 1999 Sep 1;106(3):299-314. https://doi.org/10.1016/S0269-7491(99)00108-6
78. Talarico F, Brandmayr P, Giulianini PG, Ietto F, Naccarato A, Perrotta E, Tagarelli A, Giglio A. Effects of metal pollution on survival and physiological responses in Carabus (Chaetocarabus) lefebvrei (Coleoptera, Carabidae). European Journal of Soil Biology. 2014 Mar 1; 61:80-9. https://doi.org/10.1016/j.ejsobi.2014.02.003
79. Taraslia V, Zotos S, Legakis A. Ecology of soil invertebrates in a dune ecosystem of Cyprus. In11th international congress on the zoogeography and ecology of Greece and adjacent region, Herakleion 2009 (p. 1).
80. Twardowska I. Ecotoxicology, environmental safety, and sustainable development-challenges of the third millennium. Ecotoxicology and environmental safety. 2004;58(1):3-6.
81. United Nations Environment Programme (UNEP). Phytoremediation: an environmentally sound technology for pollution prevention, control, and remediation. An Introductory Guide to Decision-Makers. Newsletter and Technical Publications Freshwater Management. Series volume 2. 2010.
82. Usero J, González-Regalado E, Gracia I. Trace metals in the bivalve mollusc Chamelea gallina from the Atlantic coast of southern Spain. Oceanographic Literature Review. 1996;10(43):1058.
83. Vercoutere K, Fortunati U, Muntau H, Griepink B, Maier EA. The certified reference materials CRM 142 R light sandy soil, CRM 143 R sewage sludge amended soil and CRM 145 R sewage sludge for quality control in monitoring environmental and soil pollution. Fresenius' journal of analytical

chemistry. 1995 Jan; 352:197-202. https://doi.org/10.1007/BF00322326

84. Wuana RA, Okieimen FE. Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. International Scholarly Research Notices. 2011;2011(1):402647. **https://doi.org/10.5402/2011/402647**
85. Xu Z, Chen Y. Aggregated intensity of dominant species of zooplankton in autumn in the East China Sea and Yellow Sea. Chinese Journal of Ecology. 1989 Aug 10(4):13. https://www.cje.net.cn/EN/Y1989/V/I4/13
86. Zhou J, Du B, Wang Z, Zhang W, Xu L, Fan X, Liu X, Zhou J. Distributions and pools of lead (Pb) in a terrestrial forest ecosystem with highly elevated atmospheric Pb deposition and ecological risks to insects. Science of the Total Environment. 2019 Jan 10; 647:932-41. *https://doi.org/10.1016/j.scitotenv.2018.08.091*
87. Azam I, Afsheen S, Zia A, Javed M, Saeed R, Sarwar MK, Munir B. Evaluating insects as bioindicators of heavy metal contamination and accumulation near industrial area of Gujrat, Pakistan. BioMed research international. 2015;2015(1):942751. **https://doi.org/10.1155/2015/942751**
88. Hamza YI. Ecotoxicological studies on heavy metals pollution at different industrial regions, Menofia Governorate, Egypt [M.Sc. thesis]. Cairo (Egypt): Faculty of Science, Al-Azhar University; 2019.
89. Hussein MA. Tenth of Ramadan City: A study in urban services. *Journal of the Faculty of Arts Research, Menoufia University*. 2020;31(122):3-26.