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Original Article

Influence of Airborne Pollution on Cu, Cr, Fe, Ni, and Zn Accumulation on Plants from Sites Around Ferrosilicon Factory, Aswan Governorate, Egypt.

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Abstract:

In this study, the effects of industrial pollution on Fe, Zn, Cu, Ni, and Cr accumulation were investigated on plants in the area around a ferrosilicon alloy factory. The sites around the plant were selected on the basis of the distance from the plant. We determined that industrial activities produce the most incorporated air pollutants. Fe, Zn, Cu, Ni, and Cr amounts were high in plant samples in the industrial area.

The concentrations of heavy metals in plants at different sampling sites varied with season, and we found that unwashed samples had greater accumulation of heavy metals than clean samples. Fe has emerged as the dominant metal, with Cr having the lowest concentration. The examined metals demonstrated the sequence as follows: Fe> Zn> Cu> Ni> Cr and the closest areas to the facility had the highest metal concentrations

There were noticeable changes in N, P, and K content between samples of washed and unwashed plants. When compared to the control location, the factory's scattered surroundings exhibited the largest N, P, and K buildup. This lends credence to the hypothesis that the manufacturing emissions are also responsible for the elevated element levels.

These results indicate the pollution from the ferrosilicon factory's existence. Where field observation revealed that the vegetation was covered with dust during all seasons at different rates.

Keywords: Air pollution. Heavy metals, Plants, ferrosilicon alloy factory

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1- Introduction

Ecosystem pollution by potentially toxic elements (PTEs) has grown to be a major worldwide issue with detrimental effects on human health. Because of their toxicity, durability, and capacity to build up in the biotic environment, PTEs pose a threat to human health. The majority of PTEs can linger in soils for a very long time since they cannot be broken down chemically or microbiologically. In addition to endangering the landsphere, they can spread to neighboring environmental spheres by biological transmission, air circulation, and water movement. **(Nieder and Benbi, 2024).**

Industrial areas in Egypt suffer from a number of environmental problems, including waste management and disposal of contaminants from the factories **(Alkhdhairi et al., 2018).** From these factories, the ferrosilicon alloys factory, which is located in Upper Egypt, north of Edfu City, Aswan Governorate. This plant is the largest integrated industrial center for the production of ferrosilicon alloys in the Middle East; its production is used in the iron and steel industries. The Edfu district had chosen to set up the plant for its proximity to the sources of electricity generation as well as to provide pure quartz ore in the area of Um Heglig **(Newman, 2007).** This plant uses quartz, coke coal, and iron oxide as raw materials. These materials contain several elements: Al, Ca, Cr, K, Mg, Mn, Ni, P, and S. Some toxic gases are also released into the atmosphere. Airborne particles settle from the ferrosilicon alloys factory, which affects the soil and plants that grow near this area. In general, heavy metal pollutants are toxic, accumulate in living organisms, and cannot be biodegraded in the environment **(Basson et al., 2007).**

Rapid industrialization, inadequate emission control, and disorganized urbanization all contribute to an increase in the release of heavy metals into the environment. Contamination of soil, water, and the atmosphere with heavy metals affects plants as well as all the organisms in their habitat**. (Onder and Dursun, 2006).**

Heavy metals from the growth medium can be absorbed and accumulated by plants. Plant roots have the ability to absorb heavy metals from the soil and transfer them to the leaves, and also Heavy metals are absorbed via the air by foliar precipitation **(Lyanguzova, 2021).** Because of the different characteristics of foliar uptake, accumulation, and translocation of atmospheric heavy metals by plants, plants are used as bioindicators and/or biomonitors of heavy metal pollution in the terrestrial environment (**Tomasevic et al. 2005**).

The main purpose of the current study is to assess the impact of the Ferrosilicon Alloy Factory, Edfu, Aswan Governorate, on the plant environment surrounding the factory. And this was done through the study of the influence of airborne pollution on Fe, Cu, Cr, Ni and Zn accumulation on plants from industrial sites, and through the study of the seasonal variations in the heavy metal levels in soil, plants, and water in the study area.

2. Materials and Methods

2.1. Study area

Ferrosilicon Alloys Factory is situated on the eastern bank of the Nile Valley north of Edfu district (25.012920° N and 32.883135° E), 110 km north of Aswan Governorate. The ferrosilicon project of the Egyptian Ferroalloys Company was built on an area of 50 acres. The

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study area around the facility offers basic information that might be utilized for pollution monitoring and as a reference for future expansion. It also examines the impact of anthropogenic activities on the level of heavy metals at various distances in the southern, eastern, and northern directions, as well as in the southeast, which is home to most agricultural lands. These areas are located between latitudes 24° 59' 20.26″ and 25° 1' 30.38″ North and longitudes 32° 52' 49.43″ and 32° 53 52.78″ East

2.2. The climate

High air temperatures, soil temperatures, relative humidity, and atmospheric pressure characterize the climate in this area. The maximum air temperature was recorded in September, while the minimum was in January; the average soil temperature was 36.96°C, and the highest relative humidity was 50.33% in January. The average annual atmospheric pressure was 1020.20 hpa in January, and the highest precipitation was 9.5 mm in May. The winds were mainly from the north or northwest. The maximum wind speed (4.07 m/s) was recorded in July, while the minimum (2.25 m/s) was recorded in December, with an average of 3.24 m/s.

2.3. Samples Collection

Plants samples were collected seasonally during the 2020 year's four periods (winter, spring, summer, and autumn). The sites around the plant were selected based on the distance from the plant, and GPS took the location coordinates (Table (1)).

Table (1): Location and Global Position System (GPS) of The Samples Sites Around The Factory.

Sample Sites	Coordinates	
	N	E
S1	25° 1' 30.38"	32° 52' 49.43"
S2	25° 1' 22.88"	32° 52' 50.63"
S3	25° 1' 12.77"	32° 52' 51.79"
S4	25° 1' 4.70"	32° 52' 52.88"
S5	25° 0' 15.03"	32° 53' 7.11"
S6	25° 0' 17.73"	32° 53' 21.58"
S7	25° 0' 4.32"	32° 53' 10.59"
S8	25° 0' 8.36"	32° 53' 26.03"
S9	24° 59' 50.60"	32° 53' 18.85"
S10	24° 59' 48.94"	32° 53' 31.08"
S11	24° 59' 51.42"	32° 53' 40.89"
S12	24° 59' 35.13"	32° 53' 28.91"
S13	24° 59' 37.88"	32° 53' 46.72"
S14	24° 59' 20.06"	32° 53' 36.99"
S15	24° 59' 21.46"	32° 53' 52.78"
S16	24° 55' 36.95"	32° 53' 23.18"

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2.4. Plant Sampling

The plant samples were collected from the same sites of soil samples. The collected plant samples were transported to the laboratory immediately in properly labeled paper bags that allow for transpiration. The following steps were done for processing the plant samples:

1- Each plant sample was divided into two parts.
2- Part one was washed with dionized water and the other was left without washing.
3- Immediate drying in an oven at 65°C for 48 hours.
4- Mechanical grinding to produce a material suitable for chemical analysis.

2.5. Methods of Plant Analysis

Total Nitrogen: was measured in plant samples after the digestion of dried plant samples by adding catalyst mixtures (K_2SO_4-Se) and concentrated H_2SO_4, then the digested sample was distilled using a micro Kjeldahl's distilling unit. After distillation, total nitrogen content was determined in the distillate **(Jackson, 1973).**

Microwave Digestion Method: the digestion of plant samples was using concentrated HNO_3 and 30% H_2O_2. (Temperature 100 °C/ vessel, ramp-10-minute, hold- 10 minute and cool 30 minutes) **(Sah and Miller, 1992).**

Total Phosphorus: was determined using the spectrophotometer at 660-nm and 420-nm wavelengths, respectively **(Jackson, 1973).**

Total Potassium was determined using the flame photometer.

Heavy Metals were determined using inductively coupled plasma (ICP) spectrometry (Model Ultima 2 JY Plasma).

3. Results and Discussion

3.1. Plant Contents of Some Nutrients and Heavy Metals:

3.1.1. Nitrogen: Within Table (2), The total N in the unwashed plant samples ranged from 2.42 to 4.94%, from 2.02 to 5.04%, from 2.35 to 3.56 %, and from 2.61 to 4.48 %, while in the washed samples it was between 2.36 and 4.77 %, from 1.95 to 4.88 %, from 2.15 to 3.09 %, and from 2.47 to 4.15 % for the winter, spring, summer, and autumn seasons, respectively. The results reveal that the unwashed plant samples had higher amounts of N than the washed samples throughout the year, as demonstrated for total N content in all seasons. These ranges appear to be high when compared to a normal (uncontaminated) sample. These results are in agreement with those recorded by **Driscoll et al., (2024),** who found that both of the reduced and the oxidized forms of nitrogen pollution can be deposited as wet or dry deposition depending on climate, and also the added fertilizers significantly increased the concentration of mineral nitrogen in soil, and these findings are in agreement with **Priya et al., (2024).**

3.1.2. Phosphorus: The phosphorus concentration in the unwashed plant samples (Table (3)) ranged from 0.33 to 0.65%, from 0.21 to 0.58 %, from 0.21 to 0.69 %, and from 0.23 to 0.56 %, whereas in the washed samples for the winter, spring, summer, and autumn seasons, it was between 0.28 and 0.40 %, from 0.17 to 0.38 %, from 0.18 to 0.54 %, and from 0.17 to 0.45

%, respectively. Every plant sample had higher P levels than the samples that had been cleaned. P levels in the vicinity of the ferrosilicon factory were high in all directions. This lends credence to the hypothesis that phosphorus pollution may originate from manufacturing emissions and be responsible for the elevated phosphorus levels. **(Azam et al., 2019).**

3.1.3. Total Potassium: According to the findings, when compared to the control location, the factory's scattered surroundings exhibited the largest K buildup. K values (Table (4)) at several locations were greater than the thresholds for potassium metal content, in accordance with **Campbell's (2000)** categorization. Approximately 40% of the unwashed plant samples had high K status, while 60% of the unwashed plant samples under investigation had medium K status, and approximately 28.3% of the washed plant samples had high K status compared to 71.7% who had medium K concentration. These findings are consistent with **El-Desoky's (2000)** study, which looked at the evaluating plants near an industrial region in North Assiut City, Egypt. The concentrations of K in a variety of plants declined with distance from the factory, and there were noticeable changes in K contents between samples of washed and unwashed plants.

Table (2): N Concentration (%) in Plant Samples.

Site NO.	The unwashed plant samples				The washed plant samples			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
S1	2.42	2.02	2.35	2.61	2.36	1.95	2.19	2.47
S2	3.44	2.25	2.39	3.08	2.92	2.02	2.32	2.86
S3	3.43	2.29	3.26	3.42	3.20	2.12	3.09	2.89
S4	3.37	2.35	2.45	3.53	3.20	2.25	2.35	3.47
S5	4.38	2.59	3.19	4.48	4.27	2.42	2.89	3.84
S6	3.82	4.84	2.99	4.46	3.65	4.00	2.15	4.15
S7	3.82	4.20	3.56	3.42	3.71	3.60	2.96	3.17
S8	3.82	5.04	2.52	4.34	3.60	4.88	2.35	4.15
S9	4.94	3.06	2.93	2.86	4.77	2.89	2.76	2.49
S10	4.32	3.40	2.56	4.17	3.20	3.06	2.22	3.87
S11	3.48	4.71	2.52	3.78	3.15	4.57	2.19	3.36
S12	4.58	4.88	2.56	3.87	3.76	4.67	2.35	3.78
S13	3.77	5.04	2.56	3.47	3.09	3.83	2.25	2.66
S14	4.72	3.06	3.13	4.09	3.60	2.93	2.99	3.81
S15	4.51	5.01	3.03	4.06	3.77	4.44	2.86	3.28
S16	2.03	1.68	1.51	1.96	2.03	1.68	1.51	1.96

Table (3): P Concentration (%) in Plant Samples

Site NO.	The unwashed plant samples				The washed plant samples			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
S1	0.48	0.28	0.21	0.23	0.37	0.24	0.19	0.21
S2	0.38	0.26	0.25	0.27	0.37	0.21	0.20	0.24
S3	0.40	0.26	0.53	0.26	0.30	0.24	0.26	0.26
S4	0.44	0.30	0.56	0.44	0.37	0.26	0.28	0.30
S5	0.39	0.58	0.69	0.56	0.30	0.38	0.54	0.32
S6	0.35	0.46	0.58	0.48	0.31	0.33	0.52	0.32
S7	0.62	0.31	0.65	0.41	0.38	0.27	0.30	0.29
S8	0.65	0.29	0.46	0.55	0.37	0.26	0.26	0.45
S9	0.52	0.29	0.58	0.32	0.40	0.26	0.26	0.31
S10	0.43	0.29	0.65	0.51	0.40	0.26	0.36	0.33

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S11	0.30	0.27	0.53	0.28	0.28	0.25	0.27	0.27
S12	0.33	0.27	0.52	0.27	0.32	0.25	0.26	0.26
S13	0.33	0.28	0.45	0.27	0.28	0.26	0.29	0.26
S14	0.42	0.34	0.49	0.26	0.40	0.28	0.26	0.25
S15	0.43	0.26	0.49	0.25	0.36	0.25	0.24	0.24
S16	0.27	0.16	0.17	0.16	0.27	0.16	0.17	0.16

Table (4): K Concentration (%) in Plant Samples.

Site NO.	The unwashed plant samples				The washed plant samples			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
S1	3.40	2.79	2.77	2.25	3.30	2.70	2.59	2.16
S2	3.70	2.83	2.95	2.26	3.20	2.70	2.62	2.11
S3	3.30	3.41	2.34	2.73	3.20	3.23	2.23	2.30
S4	3.60	3.34	2.37	3.05	3.40	3.07	2.23	2.62
S5	4.60	3.16	3.27	3.59	4.20	3.44	3.16	3.38
S6	3.90	3.38	3.09	3.16	3.00	3.01	2.94	2.91
S7	3.90	3.16	3.02	2.43	3.60	2.82	2.91	2.29
S8	2.20	2.95	2.44	3.05	2.00	2.70	2.30	2.62
S9	2.20	3.02	2.84	2.26	2.00	2.85	2.80	2.17
S10	5.50	3.95	3.09	2.59	3.10	3.56	2.73	2.55
S11	2.10	3.67	2.37	2.34	2.00	3.54	2.19	2.17
S12	3.20	3.81	2.53	2.25	2.10	3.22	2.39	2.16
S13	3.10	2.88	2.95	2.35	2.10	2.71	2.73	2.19
S14	3.20	2.77	2.55	2.73	2.80	2.62	2.37	2.44
S15	3.30	3.16	2.44	2.73	3.00	2.84	2.41	2.26
S16	1.90	2.14	2.19	2.07	1.90	2.14	2.19	2.07

3.2. Heavy metal levels in plants

3.2.1. Copper (Cu)

Cupper accumulations (Fig.1) showed that 6.7% of the uncleaned samples had high copper concentrations and were discovered in four locations, while 72.2% of the plant samples had medium copper concentrations. In the washed plant samples, the data revealed that all samples were medium in Cu concentration. Copper concentrations in the winter season varied from 5.83 to 26.20 ppm in washed plant samples, compared to 7.90 to 31.65 ppm in unwashed plant samples. Copper levels in plant samples during the spring varied from 6.50 to 25.05 ppm before washing and from 5.12 to 17.52 ppm after washing. In the summer, the amounts of Cu in plant samples varied from 7.11 to 18.28 ppm in washed plant samples and from 8.98 to 21.92 ppm. Copper content in plant samples taken during the autumn season ranged from 5.78 to 14.68 ppm in washed samples, compared to 9.16 to 17.63 ppm in unwashed samples. The WHO recommends a copper tolerance level for plants of 10 mg/kg. Data indicate that several samples of plants, both unwashed and washed, had copper levels that were relatively high for this range.

3.2.2. Iron

Fe accumulations (Fig.1) varied from 257.7 to 1315.1, 234.3 to 1495.5, 517 to 1753.4 and 252.9 to 1681.8 ppm in unwashed samples compared to 248 to 1205, 142.4 to 841.3, 391.6 to 1153.4, and 243.6 to 849.1 ppm in samples of washed plants during winter, spring, summer, and autumn seasons, respectively. The outcomes demonstrated that the iron concentration was found to be high throughout the factory and to decrease with distance. The results showed that dust considerably increased the amount of iron in plants since the plant samples that were not washed had higher levels of iron compared with those that were washed. The differences in these levels are most probably due to the deposits coming from the ferrosilicon alloys factory. These findings concur with those made public by **Ghallab (2002),** who discovered that iron concentrations in plant samples from the same industrial region varied from 100.80 to 3798.75 ppm pre-washing to 57.70 to 1320.05 ppm post-washing. Additionally, the iron levels in the unwashed plant samples were higher than those in the cleaned plant samples.

3.2.3. Zinc

At the research site, according to (Fig.1), unwashed plant samples from the winter, spring, summer, and autumn seasons, respectively, had zinc contents that ranged from 30.7 to 100, 30.61 to 74.25, 29.53 to 72.17, 30.57 to 77.37 ppm. Samples of winter, spring, summer, and autumn plants, respectively, that had been cleaned had zinc values between 23.7 to 53.21, 26.21 to 58.23, 20.41 to 53.97, 25.69 to 59.56 ppm. Based on the results, the factory's dispersed environs showed the highest Zn accumulation when compared to the control site. Some sites had Zn levels that were higher than the critical limits for zinc metal concentration. These results are in harmony with the study of the effects of industrial and urban pollution on Zn accumulation on tree leaves in Antakya, Turkey. Where **Doğanlar and Atmaca, (2011)** reported findings that were similar to those of our study. They found that urban and industrial activity increased the amount of hazardous zinc (20.7 to 94.7 ppm) on the tree leaves, and this indicated that the concentrations of some of these pollutants were increased by natural and others by anthropogenic (industry processes and traffic activity) processes.

3.2.4. Chromium

The distribution patterns of Cr in the samples of gathered plants are displayed in Fig. (1). Based on the data, chromium concentrations decreased with distance from the factory in the south, peaking at 8.71, 9.26, 8.45, and 9.02 ppm for unwashed plant samples and 6.50, 7.45, 7.10, and 7.08 ppm for washed plant samples in the winter, spring, summer, and autumn, respectively, near the factory. However, throughout the year, there were noticeable Cr concentrations in the areas north of the site. Our findings are remarkably similar to those of **Ghallab (2002),** who found that in the same study region, the greatest chromium concentration was obtained in an unwashed plant sample at 9.66 ppm and in a washed sample at 7.07 ppm, and this was near a factory. According to **Waoo et al.,'s (2014)** study, The bulk of the plant species found in industrially contaminated areas revealed large accumulations of heavy metals. This demonstrated that there is a considerable quantity of chromium that contaminates the plants in industrially contaminated areas, which is what our study found.

3.2.5. Nickel

Ni accumulations ((Fig.1)), ranged from 5.30 to 12.50, 3.20 to 16.08, 4.66 to 15.80, and 5.08 to 16.18 ppm in unwashed samples, while washed plant samples ranged from 4.30 to 10.22, 2.17 to 13.75, 4.42 to 12.42, and 3.60 to 14.16 during winter, spring, summer, and

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autumn seasons, respectively. The nickel concentration fluctuated from season to season and varied between washed and unwashed plant samples. The unwashed samples had higher nickel concentrations than the washed ones, which suggest that there has been contamination based on the recommended limit for plants from the WHO (10 ppm for nickel). The highest values were found in the plant samples located near the factory in the south direction in all seasons. The Ni concentrations fall as we get further away from the sources of the pollution. These results reveal that the majority of plant samples from industrial areas contain excess quantities of nickel, demonstrating the impact of factory dust on nickel values.

Fig. (1): (a, c, e, g and i) Heavy Metals Concentrations (mg/kg) in Unwashed Plant Samples, (**b, d, f, h and j)** Heavy Metals Concentrations (mg/kg) in Washed Plant Samples During all Seasons.

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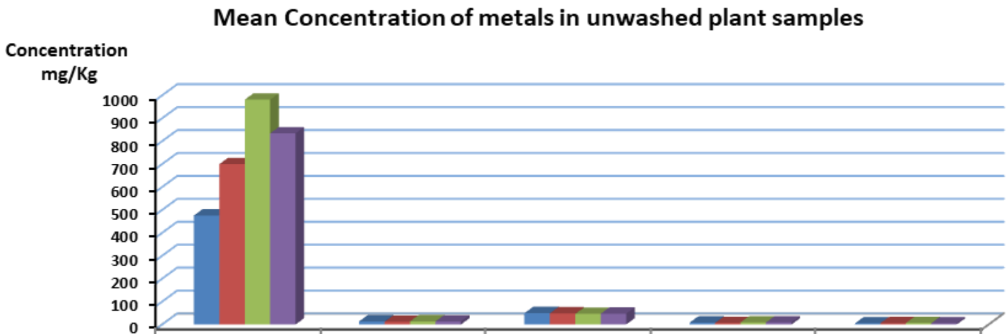
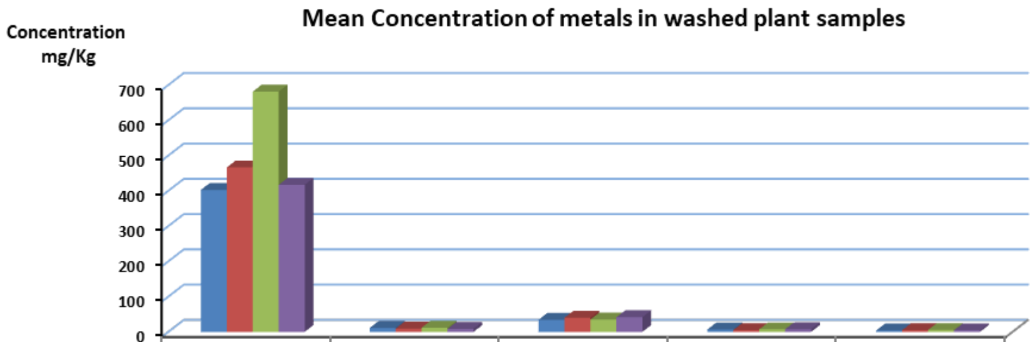
3.3. Fe, Cu, Cr, Ni, and Zn Accumulation in The Plant Samples and Their Spatial Distribution

The findings demonstrated that heavy metal concentrations varied at different sampling locations and varied seasonally, with unwashed samples always having greater quantities of heavy metals than clean samples. This indicates the pollution from the ferrosilicon factory's existence. The deposition of dust has also been observed on the soil, as the soil particles mixed with the dust can be seen in the area. **Bharti and Sharma, (2022)** reported that plants are more likely to absorb heavy metals when the soil concentration is higher.

Fe has emerged as the dominant metal, with Cr having the lowest concentration, according to the results of the presence of the metals in all of the analyzed locations, which are shown in (Fig.2)). The examined metals demonstrated the sequence as follows: Fe, Zn, Cu, Ni, and Cr. These findings showed the closest areas to the facility, in the south and north, have the highest metal concentrations.



	Fe	Cu	Zn	Ni	Cr
winter	475.7	13.9	49.6	8.63	5.17
spring	699.9	11.9	48.8	6.83	5.88
summer	981.3	13.9	46.9	9.36	6.43
autumen	834.2	13.4	47.4	9.13	5.53



	Fe	Cu	Zn	Ni	Cr
winter	402.5	11.1	34.2	6.57	3.88
spring	466.2	9.28	40.2	5.13	4.71
summer	681.2	11.6	35.1	7.22	5.32
autumen	416.9	8.54	41.6	7.62	4.49

Fig. (2): Mean Concentration of Metals for All Season in Plant Samples.

Recommendations

We recommend the necessity of using filters and activating them throughout the year on the factory chimneys for fear of the high concentrations of heavy elements accumulating in samples of environmental elements surrounding the factory, which inevitably affects the health of humans and living organisms in general and takes this agricultural area out of its suitability.

Conclusion

The urban and industrial atmosphere contains many pollutants, such as heavy metals **(Yang et al. 2024).** This study demonstrated that industrial activities caused increased heavy metal levels in the atmosphere, and these toxic substances accumulated in plants.

After processing the data, the following conclusions have been drawn:

1. The heavy metal concentrations varied at different sampling locations and varied seasonally, with unwashed samples always having greater accumulation of heavy metals than clean samples. This indicates the pollution from the ferrosilicon factory's existence. Where field observation revealed before that the vegetation of the surrounding areas of the ferrosilicon factory was covered with dust during all seasons at different rates.
2. The Fe concentration in plant tissues had reached a toxic level. The iron concentration was found to be high throughout the factory and to decrease with distance. While 98.3% of the unwashed plant samples had a high level. The results from the washed plant samples showed that 90% of the plant samples had high iron concentrations.
3. In the four seasons, 93.3, 30, 36.7% of the uncleaned samples had high Cr, Cu, and Ni concentrations, respectively. Only 90, 20%, of the washed plants had high Cr and Ni concentrations. In the washed plant samples, all samples were medium in Cu concentration.
4. The high zinc concentrations were found in 23.3% of the total unwashed samples. Only 5% of the plant samples at three sites had high zinc concentrations, according to data from the washed plant samples.

Overall, the results support the idea that industrial activity is the cause of the contamination. After seeing this result, we should pay more attention to the heavy metal pollution problem around this area. Environmental pollution should be controlled and repaired to ensure the safety of surrounding residents.

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