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A Review of Dioxin Contamination and Health Risks In Egypt

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ABSTRACT

This study aims to assess dioxin contamination in Egypt by compiling studies that have analyzed dioxin pollutants in air, water, soil, and food in the country to determine exposure levels and potential health risks. Samples were collected from multiple locations, including industrial, agricultural, and urban areas, to evaluate dioxin concentrations. The results indicate that industrial activities and poor waste management, particularly open burning and uncontrolled emissions, are the main sources of environmental dioxin pollution. Soil and water samples near industrial areas exhibited high contamination levels, and bioaccumulation was detected in food products such as dairy, fish, and meat. This raises concerns about dietary exposure, as continuous consumption of contaminated food may lead to severe health consequences. Health risk assessments indicate that chronic exposure to dioxins may result in hormonal imbalances, immune system suppression, reproductive disorders, and an increased risk of cancer. Vulnerable groups, such as children and pregnant women, are at higher risk due to the long-term accumulation of these compounds in their bodies. Dioxins, a group of persistent and toxic environmental pollutants, pose significant health risks. While studies in Egypt have focused on food contamination, including dairy products, fish, and meat, no comprehensive dietary intake assessments exist to fully evaluate health risks .These findings suggest urgent regulatory measures are needed to reduce dioxin contamination in Egypt. This requires strengthening environmental policies, improving waste management systems, and enforcing strict controls on industrial emissions. This study emphasizes the importance of intervention to mitigate the long-term impacts of dioxin pollution in Egypt.

Keywords: Dioxins ; Ecosystems; Industrial emissions; Bioaccumulation; Health Risk Assessment.

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INTRODUCTION

Dioxins are environmental pollutants. They belong to the so-called dirty dozen – a group of dangerous chemicals known as persistent organic pollutants (POPs). Dioxins are of concern because of their highly toxic potential. Experiments have shown they affect several organs and systems (***Sah, & Joshi, 2011***).

Once dioxins enter the body, they last a long time because of their chemical stability and their ability to be absorbed by fat tissue, where they are then stored in the body. Their half-life in the body is estimated to be 7 to 11 years. In the environment, dioxins tend to accumulate in the food chain. The higher an animal is in the food chain, the higher the concentration of dioxins (***Tuomisto, Jouko 2019).*** The chemical name for dioxin is 2,3,7,8- tetrachlorodibenzo para dioxin (TCDD). The name dioxins are often used for the family of structurally and chemically related polychlorinated dibenzo para dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Certain dioxin-like polychlorinated biphenyls (DL-PCBs) with similar toxic properties are also included under the term dioxins. Some 419 types of dioxin-related compounds have been identified but only about 30 of these are considered to have significant toxicity, with TCDD being the most toxic (***Szajneret al., 2021).***

Effects of Dioxin on human health

The late 1970s and early 1980s saw a significant increase in public awareness of the risks of dioxins presented to public health. Narratives of sick veterans exposed to dioxins from Agent Orange, an herbicide and defoliant used during the Vietnam War, were a common sight in newspapers and television shows (***Young, 2019***). The toxic potency of dioxins and dioxin-like compounds are variable in humans and other mammals. To estimate the total body burden, the toxic equivalency factor (TEF) has been defined for each compound by the World Health Organization (WHO) ***(Van den Berg et al., 2006).*** The body burden of these molecules is calculated by the sum of toxic equivalency (TEQ) of each compound (TEF × concentration of the compound) ***(La Rocca et al., 2008).***

Exposure to high TEQ concentration of dioxins manifests various acute systemic signs and symptoms, including general malaise, cough/sputum, diarrhea, headache, nausea, arthralgia, and pain/dysesthesia of extremities (***Saurat et al., 2012***).Short-term exposure of humans to high levels of dioxins may result in the most prominent clinical findings of dioxin which are skin lesions, such as chloracne and patchy darkening of the skin, and altered liver function. Chloracne and hyperpigmentation which occurred in Yusho ,Japan in 1968 by mass food poisoning with high concentrations of PCDFs and related compounds ***(Mitoma et al., 2018)***. In humans, the liver plays a central role in metabolizing and facilitating the excretion of these toxic compounds through a series of enzymatic processes. Once dioxins enter the human body—primarily via ingestion—they are distributed into fatty tissues and slowly metabolized, predominantly by liver enzymes. The liver utilizes cytochrome P450 enzymes, especially CYP1A2, in Phase I metabolism to oxidize dioxins into more polar metabolites. This is followed by Phase II conjugation reactions involving glutathione-S-transferase (GST), which enhance solubility and promote biliary excretion (***Wu et al., 2024***). Despite these mechanisms, dioxins are highly resistant to metabolic degradation, resulting in a long biological half-life in humans, ranging from 7 to 11 years (***WHO, 2016***). This persistence contributes to their cumulative toxicity, endocrine disruption, and potential carcinogenicity (***Zhang et al., 2024***).

Because these compounds are extremely lipophilic and structurally stable, high concentrations of PCDF are still detectable in the blood of those exposed, even 50 years after the outbreak***(Furue & Tsuji, 2019)***. The Yucheng illness, a mass poisoning in Taiwan caused by PCDF; and the poisoning of former Ukrainian President Victor Yushchenko with TCDD. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. Being a lipophilic chemical that resists degradation, dioxins can reach the endocrine pancreas *in vivo*, which may have important implications for islet cell function and survival***(Hoyeck et al., 2020)***. Epidemiological studies have reported an association between exposure to persistent organic pollutants (POPs) and increased diabetes incidence, and decreased insulin secretion in humans***(Lee et al., 2017)* .**

Chronic exposure of dioxins has resulted in several types of cancer ***(Xu et al., 2016)*** TCDD was evaluated by the WHO's International Agency for Research on Cancer (IARC) in 2012 and was identified as a known human carcinogen. However, TCDD does not affect genetic material and there is a level of exposure below which cancer risk would be negligible. Current findings on cancer can be summarized as follows: there is sufficient evidence of an association between dioxins and soft tissue sarcomas, Hodgkin's lymphoma, and non-Hodgkin's lymphoma; there is limited or suggestive evidence of an association between dioxins and bladder cancer, laryngeal cancer, cancers of the lung, bronchus, and trachea, prostate cancer, multiple myeloma, and A L amyloidosis; there is inadequate or insufficient evidence to determine whether there is an association between dioxins and any other specific type of cancer ***(National Academies of Sciences, Engineering, 2018).*** Due to the omnipresence of dioxins, all people have background exposure and a certain level of dioxins in the body, leading to the so-called body burden. Current normal background exposure is not expected to affect human health on average. However, due to the high toxic potential of this class of compounds, efforts are needed to reduce current background exposure ***(Peivasteh-Roudsari et al., 2023)***. However maternal exposure to dioxins can affect fetal growth and infant development ,as the developing fetus is most sensitive to dioxin exposure ***(Long et al., 2022).***

Environmental Sources in Egypt

Barakat et al (2013) reported that Organochlorine contamination in the Mediterranean coastal environment of Egypt was assessed based on 26 surface sediments samples collected from several locations on the Egyptian coast, including harbors, coastal lakes, bays, and estuaries. The distribution and potential ecological risk of contaminants is described. Organochlorine compounds (OCs) were widely distributed in the coastal environment of Egypt. Concentrations of PCBs, DDTs, and chloropyrifos ranged from 0.29 to 377 ng g^{-1} dw, 0.07 to 81.5 ng g^{-1} dw, and below the detection limit (DL) to 288 ng g^{-1} dw, respectively. Other organochlorinated pesticides (OCP) studied were 1–2 orders of magnitude lower. OCP and PCBs had higher concentrations at Burullus Lake, Abu Qir Bay, Alexandria Eastern Harbor, and El Max Bay compared to other sites. OCP and PCB contamination is higher in the vicinity of possible input sources such as shipping, industrial activities and urban areas. PCB congener profiles indicated they were derived from more than one commercially available mixture. The ratios of commercial chlordane and heptachlor metabolites indicate historical usage; however, DDT and HCHs inputs at several locations appear to be from recent usage. The concentrations of PCBs and DDTs are similar to those observed in sediments from coastal areas of the Mediterranean Sea. Ecotoxicological risk from DDTs and PCBs is greatest in Abu Qir Bay, Alexandria Harbor, and El-Max Bay.

Persistent organic pollutants represent about 95 % of the industrial sector effluents in Egypt that according to the study conduct by ***Dahshan et al in 2016***. Contamination of the River Nile water with various pesticides poses a hazardous risk to both human and environmental compartments. Therefore, a large-scale monitoring study was carried on pesticides pollution in three geographical main regions along the River Nil water stream, Egypt. Organochlorine pesticides mean concentrations along the River Nile water samples were 0.403, 1.081, 1.209, 3.22, and 1.192 μg L−1 for endrin, dieldrin, p, p'-DDD, p, p'-DDT, and p, p'-DDE, respectively. Dieldrin, p, p'-DDT, and p, p'-DDE were above the standard guidelines of the World Health Organization. Detected organophosphorus pesticides were Triazophos (2.601 μg L−1), Quinalphos (1.91 μg L−1), fenitrothion (1.222 μg L−1), Ethoprophos (1.076 μg L−1), chlorpyrifos (0.578 μg L−1), ethion (0.263 μg L−1), Fenamiphos (0.111 μg L−1), and pirimiphos-methyl (0.04 μg L−1). Toxicity characterization of organophosphorus pesticides according to water quality guidelines indicated the hazardous risk of detected chemicals to the public and to the different environmental compartments. The spatial distribution patterns of detected pesticides reflected the reverse relationship between regional temperature and organochlorine pesticides distribution. However, organophosphorus was distributed according to the local inputs of pollutant compounds (***Dahshan et al., 2016)***.

Poly- and perfluoroalkyl substances PFASs are per-fluoroalkyl sulfonates (PFSAs) and per-fluoroalkyl carboxylates (PFCAs) of which the per-fluorooctane sulfonate (PFOS) and per-fluorooctanoic acid (PFOA) are widely detected in the environment, wildlife and humans from around the world ***.Shoeib et al (2016)*** were carried out a study to examine (**PFAS**) substances from 17 homes, 5 workplaces and 9 cars in Cairo along with paper and cardboard food contact materials purchased from retailers and grocery stores in Cairo. Paper and cardboard materials included fast food sandwiches wrappers for burgers; paper boxes for French fries, pizzas and sandwiches; non-stick baking cups; microwave bags for popcorn and soup cups. PFAS levels in dust ranged from 1.09 to 55.2 ng/ng and included fluorotelomer alcohols (FTOHs) > perfluorooctane sulfonamidoethanols (FOSEs) > perfluorooctane sulfonamides (FOSAs), > fluorotelomer acrylates (FTAs). The 8:2 FTOH substance was the dominant substance followed by 6:2 FTOH and 10:2 FTOH. Similar levels and substances were observed in workplaces and cars. The authors note that the prevalence of FTOHs could reflect their use in consumer products. PFOS (4.09 ng/g) and PFOA (2.16 ng/g) were also dominant substances in dust and perfluorohexanoic acid (PFHxA) (21% of samples), perfluorononanoic acid (PFNA) (13% of samples), and perfluorodecanoic acid (PFDA) (29% of samples) were also detected. PFAS levels in dust in Egypt are lower than in other countries and the authors note that imported wall to wall carpeting is typically not used in Egyptian homes while locally manufactured carpets and furniture which are typically not treated with PFAS substances are commonly employed. The researchers analyzed for a variety of polyfluoroalkyl phosphates esters (PAPs) that are PFAS substances commonly used in food contact paper. There was a low detection frequency of these substances in packaging, but the 6:2 monoPAPs and 8:2 monoPAPs were detected in a French fries cardboard box and two sandwich wrapping papers respectively. PFOA was found in 79% of the food contact samples with a median concentration of 2.4 ng/g. The highest PFOA levels were found in two food paper wrappers at 65 ng/g and 94 ng/g. These two particular samples also showed higher levels of PFHxA, PFNA, PFDA and perfluoroundecanoic acid (PFUnA) . PFOS was found in 58% of the food contact samples with a median concentration of 0.29 ng/g.

In the same year ***ElShazly et al (2016)*** were showed that Manzala Lake, as one of the main Egyptian wetland ecosystems, is facing risks of pollution. An *in vitro* cytotoxicity test using a mammalian cell line was employed to determine the toxicity of multiple pollutants in the water and *Tilapia zillii* fish sampled from the lake. The concentrations of seven polychlorinated dibenzo-*p*-dioxins and ten polychlorinated dibenzofurans were investigated in water and muscle of the fish in 2014. Cytotoxicity testing showed that the percentage inhibition of cell viability in the studied sites ranged between 56.16% and 83.22%. Dioxin analysis indicated that the average concentrations of 1,2,3,4,6,7,8,9-octachlorodibenzo-*p*-dioxin, 1,2,3,4,7,8-hexachlorodibenzofuran, 1,2,3,4,6,7,8-heptachlorodibenzofuran and 1,2,3,4,6,7,8,9-octachlorodibenzofuran were higher than the toxic equivalence quotients (TEQs) set by the World Health Organization (WHO) in all water and fish muscle samples; however, the average concentration of 2,3,7,8-tetrachlorodibenzofuran was higher only in fish muscle samples. The bioaccumulation factor (BAF) ranged dramatically between 2 and 58.5 for the detected dioxins. Adverse human health effects through the consumption of fish are not expected, because dioxin levels in fish muscle are deemed safe for human consumption. Implementation of a strategic multidisciplinary action plan is strongly recommended to sustain this delta wetland ecosystem (***ElShazly et al., 2016)***.

A total of 24 irrigated water samples were collected from different irrigation canals which are adjacent to industrial areas from six Egyptian governorates (Bani Swef, El-Giza, El-Sharkeya, El-Menoufeya, El-Gharbeya, and Alexandria). The study shows that irrigation water canals were contaminated with low levels of PCDDs/PCDFs, which were 0.95 pgWHO-TEQ/l, and the total of PCDD/PCDFs and dl-PCBs were 2.06 pgWHO-TEQ/l with contamination ranging between 0.88 to 2.97 pgWHO-TEQ/l while the levels of indicator PCBs were 18.52 ng/l and ranged between 0.39 to 165.6 ng/l. The most predominant dioxins congeners were **Heptachlorodibenzo-*para*-dioxin** (HpCDD), Octachlorodibenzo-p-dioxin (OCDD) , **Heptachlorodibenzofuran** (HpCDF), and octachlorinated dibenzofuran (OCDF) while for **DL** -PCBs were PCB105 and PCB118, and for NDL-PCBs was PCB138. The areas with recent urbanization and industrialization were more contaminated with PCBs than the unindustrialized area. Lightly to moderately chlorinated congeners dominated the PCB profiles. The major sources for these contaminants were fire bricks followed by textile industries closer to the sampling sites located. The detected pattern was found to be similar to the patterns reported in the air by other studies. Although the concentrations of the studied POPs are found to be low in irrigated water, it may be considered as a potential source of soil pollution due to their accumulation process in the agricultural land and may lead to risk on human health by consuming the agricultural products irrigated by contaminated water (***Abd El-Rahman et al ., 2019)***.

Dioxins in Dietary Sources in Egypt

More than 90% of human exposure to dioxins is through the food supply, mainly meat and dairy products, fish, and shellfish. Once dioxins enter the body, they last a long time because of their chemical stability and their ability to be absorbed by fat tissue, where they are then stored in the body (**WHO 2023**).

Helwan is one of the highest levels of dioxins ever measured in chicken eggs. Dioxins in eggs from Helwan exceeded the European Union (EU) limit by more than 40-fold. The level of polychlorinated biphenyls (PCBs) in the eggs exceeded the proposed EU limit by almost 5-fold. In addition, significant levels of hexachlorobenzene (HCB) were also observed. Potential existing dioxin sources in Helwan include: the metallurgical industry, uncontrolled burning of the wastes and/or cement kilns. Since the pattern of dioxins in eggs was dominated by furans (PCDF), it is likely that the sources came mainly from combustion. This suggests that the steel industry is a significant source of dioxins seen here, though other combustion sources cannot be excluded (**DiGangi, and Petrlik, 2005)**.

Dioxin, Dioxin–Like PCBs and Indicator PCBs in Some Medicinal Plants Irrigated with Wastewater in Ismailia, Egypt" investigates the presence of dioxins and PCBs in medicinal plants irrigated with wastewater1. The study focused on three commonly used medicinal plants: henna, rosemary, and moghat. The research found that all wastewater irrigated samples showed higher content of the studied contaminants than freshwater irrigated samples, except for moghat, which had similar content regardless of the type of water used for irrigation.The concentrations of PCDD/Fs, DL-PCBs, and NDL-PCBs were determined using GC/HRMS. The levels of PCB TEQ ranged from 0.005 to 0.76 pg/g wet w. In descending order, rosemary, henna, and moghat had the highest concentrations of total TEQ (PCDD/Fs DL-PCBs)1. The study concluded that wastewater irrigation could lead to an increase in the concentration of these contaminants in medicinal plants, posing a potential health risk (**Loutfy, etal., 2010)**.

Another study was conducted by **Loutfy, etal., 2007** to determine the Concentrations of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyl (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in butter, seafood and meat and feed samples (chicken, cattle and fish) purchased from Ismailia city as previous one . In this study, butter samples showed the highest contamination levels of PCDD/Fs and PCBs. The highest contamination levels of PCDD/Fs and PCBs were found in butter samples. The butter TEQ content is several times higher than that reported in all EU countries and exceeded the EU limits, while the PCDD/F levels in seafood and the feed samples are far below the current EU limit. Generally, congener profiles in the food samples reflect the non-industrialized nature of the city and suggest solid waste burning as a significant source of emission. Nevertheless, the profiles for butter suggest an impact from various sources. Also, Benzo(*a*)pyrene (B*a*P) has been detected in the food samples; butter showed the highest contamination which exceeded the EU standard set for fats and oil. Fingerprints of PAHs suggested both petrogenic and pyrolytic sources of contamination (**Loutfy, et al., 2010)**. **El-Kady et al., 2007** was to investigate The levels of organ halogenated contaminants, i.e. PCBs, PCDDs and PCDFs were determined in sediment and fish samples collected from different locations in the River Nile, Egypt. Thirty-six sediment and eighteen fish samples were carried out during a period of 12 months from February 2003 to February 2004. The results indicated that the PCB and PCDD/F mean concentrations in sediment samples ranged from 1461 to 2244 and from 240 to 775 pg g-1 dry wt basis, respectively. The mean concentration of PCBs and PCDD/Fs in fish samples were found to be in the range from 695 to 853 pg g-1 fresh wt for PCB congeners and from 27.7 to 121 pg g-1 lipid for total PCDD/Fs. Moreover, the concentrations of both PCBs and PCDD/Fs were found to be different at different locations along the river Nile. It could be concluded that the contamination of the river Nile is within the permissible limits set by the FDA and the Egyptian Standards for fish and shellfish.

Another study on Samples of butter, cream, and white cheese were collected from the city of Ismailia, Egypt, and analyzed for polychloro dibenzo-*p*-dioxins, pentachloro dibenzo-*p*-furans, and dioxin-like polychlorinated biphenyl, PCBs. Butter samples had the highest mean content of PCDD/F and dioxin-like PCBs. Butter samples were the most contaminated samples in all dairy products analyzed in this study, whereas white cheese samples were the least contaminated. The spectrum of congeners detected in butter and cream were similar whereas the spectrum of congeners detected in white cheese was differed and below WHO toxic equivalency . The estimated bodyweight-normalized intake levels of PCDDs/Fs and dioxin-like PCBs in butter, cream, and white cheese in Egypt were 0.15, 2.92, and 0.95 pg WHO-TEQ/kg/day, respectively, based on an average bodyweight of 60 kg (**Ahmed et al., 2007)**.

Another study was conducted in 2012 to investigate dioxin exposure in Egyptian baby food . The Dioxin profile analysis was useful as a fingerprint to suggest the source of dioxin contamination. The congener profiles of 17 PCDD/PCDFs in infant-formula milk, hence the 75.5% of PCDF levels contributed in total TEQ account of the toxicity in infant-formula milk while 24.5% for PCDD levels. Moreover, the 2,3,7,8-TCDD and 1,2,3,7,8-PeCDD congeners were the most abundant congeners of total PCDD congeners while the 2,3,4,7,8-PeCDF and 1,2,3,4,7,8-HxCDF congeners were the most abundant congeners of total PCDF. While, Dioxin Tolerable Daily Intake (TDI) was estimated to be within the value is consistent with tolerable intakes derived using WHO: 1-4pg WHO TEQ /kg bw/day. Furthermore, dietary exposure to dioxin of exclusively formula-fed infants was assessed each month from 0 to 24 months and estimated dietary exposure more than 6 months of age was always below the lowest range of the TDI of 1 pg WHO-TEQ kg-1 .bw. d-1 . This study gives useful data for TDI data on the daily intake permitted to Egyptian children to assess the risks and benefits of infant formula in Egypt for ages from newborns to age two years (**Nabil, et al 2012)**.

Also El-Nawawy, etal., 2016 **was** investigated the presence of polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs), and dioxin-like PCBs (dl-PCBs) in 35 pooled raw cow milk samples and 59 animal feedstuffs samples collected from various regions of Egypt. This study finding showed that animal feed have often been reported as the major source to the PCDD/Fs and dl-PCBs intake into the cow milk chain, which characterized in parallel by the total TEQ (dioxin and dl-PCBs). Data revealed that the general exposure of the population in Egypt to the main highest persistent organic pollutants was carried through cow milk and animal feedstuffs intake (***El-Nawawy, et al., 2016)***.

Another study was conducted on orange samples from different governorates in Egypt and analyzed them for dioxins, specifically polychlorodibenzo-p-dioxins (PCDDs) and polychlorodibenzofurans (PCDFs) The mean concentration of ΣPCDD/Fs in orange samples was1.8596 pg/g whole weight (w.w.). The main derivative was 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD). The study also calculated the Toxic Equivalency (TEQ) concentrations of PCDD/Fs. Overall, the PCDD/F levels in orange were lower than the maximum permissible limits set by Egyptian Standardization and the European Community. The study mentioned that estimated daily intake of ΣPCDD/Fs for Egyptian consumers was below the acceptable daily intake by the World Health Organization (**Khalil, et al., 2017)**.

On another hand. **Abd-elkhalik et al.,2021** was conduct a survey for analysis of dioxin-like polychlorinated biphenyls (dl-PCBs) in thirty human milk samples collected from Qalyubia governorate, Egypt (2016-2018). All dl-PCBs congeners were detected in all collected samples. Significant correlations were observed between total dl-PCBs (TEQ), age, and numbers of deliveries. the non-ortho PCB congener (PCB 126) was found at elevated concentrations. The mean TEQ concentrations of non-ortho and mono-ortho PCBs in the breast milk of the primiparous mothers were 7.30 and 0.20 pgTEQg1 lipid, respectively. On the other hand, multiparous mothers have a mean TEQ concentration for these dl-PCBs (non-ortho and mono-ortho PCBs) of 6.1 and 0.3 pg TEQ g-1 lipid, respectively. The most found dl-PCBs were PCB-118 and PCB-156, both account 64.9% from ΣPCBs concentrations without TEF. Estimation of infant daily intakes (EIDI) showed that they are at high risk of adverse effects caused by PCBs. This study highlights the presence and potential risks of dl-PCBs in human milk, emphasizing the need for regular monitoring and further research (**Abd-elkhalik etal., 2021)**.

CONCLUSION

Dioxin contamination in Egypt presents a significant environmental and public health concern due to its persistence, bioaccumulation, and toxicity. This study highlights that industrial activities, improper waste disposal, and uncontrolled emissions are major contributors to dioxin pollution, leading to elevated concentrations in air, water, soil, and food. The presence of dioxins in commonly consumed food products raises serious concerns regarding dietary exposure and long-term health risks.

The findings indicate that chronic exposure to dioxins may lead to severe health consequences, including endocrine disruption, immune system impairment, reproductive issues, and an increased risk of cancer. Vulnerable populations, such as children and pregnant women, are particularly at risk due to prolonged bioaccumulation. To mitigate these risks, urgent regulatory measures must be implemented to control emissions of dioxin, improve waste management, and enforce stricter environmental policies. Strengthening monitoring programs and conducting further research on dioxin distribution and exposure pathways are essential steps toward reducing contamination. Additionally, raising public awareness and promoting safer industrial and agricultural practices can significantly minimize dioxin-related hazards.

This study underscores the need for immediate action to reduce dioxin pollution in Egypt and protect both environmental and human health. Implementing sustainable waste management strategies and adopting cleaner production technologies will be crucial in preventing further accumulation of these hazardous compounds in the ecosystem.

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Conflicts of Interest

The authors declared that there is no conflict of interest regarding the publication of this paper.

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