Tropical Environment, Biology, and Technology

Review
Volume 5(1), 2025, 40–50
https://doi.org/10.53623/tebt.v3i1.630

Sources, Fate, and Transport of Endocrine-Disrupting Chemicals in Urban Soils of Vietnam: Challenges for Sustainable Urban Development

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SUBMITTED: 8 March 2025; REVISED: 28 April 2025; ACCEPTED: 8 May 2025

ABSTRACT: The rapid growth of the human population in recent years significantly accelerated urbanization across ASEAN countries. Among them, Vietnam emerged as one of the fastest-developing nations, undergoing swift industrial expansion and urban development. While this progress brought economic benefits, it also posed serious environmental challenges, most notably, the increasing presence of endocrine-disrupting chemicals (EDCs) in the natural environment. These harmful pollutants, often derived from industrial processes, pharmaceuticals, pesticides, and domestic waste, infiltrated ecosystems through air, water, and particularly soil. The core problem addressed in this study was the accumulation of EDCs in urban soils, which served as major reservoirs and posed long-term risks to both ecological systems and public health. Studies linked EDC exposure to hormonal imbalances, reproductive disorders, developmental issues, and even certain cancers in humans and animals. In addition, EDCs disrupted soil biodiversity, impaired microbial communities, and threatened species dependent on soil ecosystems. The accumulation of these compounds in Vietnam's urban soil was especially concerning due to the country's rapid industrialization and weak environmental regulations. This study aimed to provide a focused overview of the occurrence, sources, and impacts of EDCs in Vietnam's urban soils and to explore potential mitigation strategies suited to the nation's socio-industrial context. Key findings highlighted the role of urban soil as a critical sink for persistent pollutants, the urgent need for regulatory enforcement, and the importance of integrated waste management. In conclusion, Vietnam's continued development must be accompanied by proactive environmental strategies to reduce EDC contamination and safeguard ecosystem health. Future research should prioritize site-specific monitoring, the development of sustainable remediation technologies, and the evaluation of regulatory frameworks to better manage EDC risks.

KEYWORDS: EDCs; Vietnam; urban soil; heath problem

1. Introduction

As predicted by the 2019 Revision of the World Population Prospects, the world population by the end of 2020 reached 7.6 billion [1]. This indicated that human population growth had made a significant leap compared to the 1 billion people in the 1800s [2]. This massive growth began when the population growth rate increased significantly, three times faster than in previous human history. The main reasons for this increase were the decline in mortality rates and the rise in birth rates, driven by modern medical advancements and more reliable access to food, water, and shelter [3]. Among all countries, Vietnam stood out as one of the main contributors to global population growth, with a rate of 1%, which was relatively high compared to other ASEAN nations [4]. To meet the demands of this growing population, more houses and buildings were constructed, ushering in a new era of urbanisation. The development of progressive urbanisation, new technologies, and an industrial boom in developing countries—especially Vietnam—accelerated environmental pollution. This was mainly due to human activities in industrial, pharmaceutical, agricultural, and chemical sectors, which led to the presence of pollutants in various environmental media.

Among these pollutants, a unique category known as endocrine-disrupting chemicals (EDCs) emerged as a significant concern in human society. EDCs are exogenous substances that interfered with the production, release, transport, metabolism, binding, action, or elimination of natural hormones responsible for regulating cell development and maintaining homeostasis [5]. Large amounts of EDCs caused serious health problems across species. In humans, they were associated with reduced sperm production, cancer, and abnormal testicular development. In animals, they led to low fertility, feminisation, demasculinisation, and weakened immunity [6]. EDCs primarily appeared in industrial, household, and agricultural environments. Examples included dioxins (PCDD, PCDF), bisphenol A, polychlorinated biphenyls (PCBs), steroid sex hormones, metal complexes, polyaromatic hydrocarbons (PAHs), alkylphenol ethoxylates, chlorinated organic pesticides, synthetic musk compounds, gasoline additives, pharmaceutical residues, non-ionic surfactants, brominated flame retardants (BFRs), derivatives of phthalates, and personal care products. However, most EDCs were not subject to legal regulation despite their significant health impacts. Only four types—dioxins, PCBs, PAHs, and chlorinated organic pesticides—were classified as regulated pollutants, while the rest remained unregulated. These unregulated pollutants were referred to as newly emerging pollutants, as they originated from new technologies or products developed to meet modern human demands [7]. Their unregulated status made them especially dangerous, as their production and environmental release were not limited.

According to research, Vietnam had established 325 industrial parks covering approximately 94,900 hectares, primarily located in Bac Ninh, Ho Chi Minh City, and Thanh Hoa. Additionally, the country's industrial production grew by 5.4% year-on-year in October

2020, even during the global COVID-19 pandemic [8]. This growth reflected the Vietnamese government's strong emphasis on industrial development and urbanisation [9]. Although these trends were promising economically, they raised critical environmental concerns, especially regarding the emergence and proliferation of EDCs. EDCs primarily originated from industrial processes and urbanisation-related activities. With many pollutants stemming from the manufacturing sector, Vietnam faced a growing threat of widespread EDC contamination [9, 10]. The problem was compounded by the fact that many industries were unaware that their products contained EDCs, largely due to vague or insufficient regulatory guidelines. Once released, these chemicals dispersed through the air, water, and soil, with urban soil acting as a major sink for EDC accumulation. This was particularly alarming given the soil's high retention capacity and the potential for long-term ecological and health effects on both humans and terrestrial organisms [10]. This review aimed to provide a comprehensive overview of EDCs in Vietnam's urban soils by examining their occurrence, distribution, environmental and health impacts, and current mitigation strategies. Future studies should focus on improving regulatory frameworks, developing cost-effective remediation technologies, and enhancing monitoring systems to prevent further accumulation and exposure to EDCs in urban environments.

2. Overview of EDCs in Vietnam

EDCs in the soil originated from various sources such as industrial emissions, municipal wastewater, building materials, agricultural runoff, solid wastes, and even mining (Table 1). Researchers found that small amounts of EDCs existed in the effluent of sewage treatment plants, indicating that conventional treatment processes could not completely remove EDCs from sewage [9–12]. Another study demonstrated that the presence of EDCs, such as natural estrogens (17 β–estradiol) and synthetic estrogens, in sewage effluent had significant health impacts on fish when discharged into rivers.

Table 1. Overview of the sources, impacts, and references associated with EDCs.

Source of EDCs	Description/Origin	Impact on Urban Soil and Environment	References
Sewage Treatment Plant Effluent	Effluent from sewage treatment plants containing residual EDCs	EDCs from treatment plants may remain in the effluent and discharge into rivers, affecting agricultural soil and water used for drinking and irrigation.	[9–12]
Agricultural Activities	Pesticides, sewage biosolids, and animal waste (estrone, 17 β–estradiol from livestock)	Chemicals used in agricultural activities can leach into urban soils, leading to soil contamination.	[13–16]
Construction Materials	Paints, caulking, flame retardants, and PCBs in building materials	Building materials may release EDCs during or after construction, contaminating urban soil.	[17]
Solid Waste	Food, personal care products, and packaging materials (plastic)	Solid waste containing EDCs from packaging, food, personal products, and toys can contribute to soil contamination.	[18–21]
Treated Drinking Water	Water from contaminated rivers	Endocrine disruptors in drinking water may be a source of EDCs in the urban environment, especially in urbanized areas relying on contaminated rivers.	[23]
Industrial Emissions	Emissions from chemical, plastic, and manufacturing industries	Increased chemical production contributes to EDCs in the environment, correlating with higher endocrine disease rates.	[24]
River Pollution	Discharge from medical, industrial, and domestic wastewater	Rivers like KimNguu and CauBay in Hanoi are polluted with high concentrations of EDCs, affecting river sediment and, eventually, urban soil.	[25, 26]
Urbanization	Expansion of urban areas leading to higher water usage from polluted rivers	Urbanization and agricultural activities increase the likelihood of EDCs leaching into urban soil, which may affect the ecosystem and biodiversity of the urban environment.	[27–29]

Furthermore, agricultural activities contributed to urban soil EDC contamination through the widespread use of chemical pesticides, land application of sewage biosolids, and the use of animal wastes containing large amounts of estrone and 17 β–estradiol excreted by livestock [13, 14]. These harmful hormones were especially prevalent in the waste of pregnant livestock or laying poultry [15, 16]. Due to urbanisation, most agricultural activities depended on chemical pesticides and animal waste-based fertilizers, leading to the continuous accumulation of EDCs on the soil surface and deeper layers over time.

In addition, studies showed that EDCs had been commonly used in furnishings and building materials over the past 15 years. These included paints, caulking, and surface coatings; chlorinated and brominated flame retardants in electronics, textiles, and furniture; and PCBs in electrical equipment [17]. This suggested that construction materials were also sources of EDCs in urban soil, both during and after construction phases.

Solid waste was another important source of EDCs in urban soil, as it included food waste, personal care products, and daily consumer goods. Personal care products such as lotions, soaps, cosmetics, and fragrances contained EDCs [18, 19]. In food, EDCs came from packaging materials like plastics [20, 21]. Additionally, some processed foods contained EDCs due to the manufacturing processes and preservatives with endocrine-disrupting properties [22].

Moreover, treated drinking water was also identified as a source of EDCs, since it was often sourced from rivers containing these pollutants. This was confirmed by Wee and Aris, who reported that EDC concentrations in tap water ranged from 0.2 ng/L to 5,510 ng/L, while the highest concentration of 28,000 ng/L was found in well water in India [23]. However, EDC exposure was greatest in heavily contaminated environments where industrial waste leached into the soil. Research showed that global chemical industry sales increased dramatically over time [24]. Similarly, plastic production rose from 50 million tons in the 1970s to 300 million tons in 2013. This increase in chemical manufacturing was paralleled by a rise in endocrine-related diseases, including a more than 30% increase in preterm birth rates in the United Kingdom, the United States, and Scandinavia since 1981.

In Vietnam, EDCs often migrated from riverbanks to urban soil due to the lack of adequate wastewater treatment facilities. Hanoi, the capital, was a prominent example of this environmental issue, as one of the most highly urbanised cities in the country. As previously mentioned, densely populated and industrialised areas produced larger amounts of EDCs. Since sewage treatment plants could not fully eliminate EDCs from effluents, the pollutants were discharged into major rivers in Hanoi.

One such river, the Kim Nguu River, was heavily polluted by medical, industrial, and domestic wastewater. Studies reported that concentrations of EDCs, such as polybrominated diphenyl ethers (PBDEs), in Kim Nguu River sediments ranged from 4.49 to 10.68 ng/g dry weight—much higher than levels found in Thi Nai Lagoon, Vietnam, or in Hong Feng, China [25]. Additionally, Σ6PAE concentrations in the Kim Nguu River ranged from 23.31 to 199.51 ng/g dry weight. Another Hanoi river, the Cau Bay River, also exhibited serious EDC contamination. Research by Toan and Quynh revealed that PCB concentrations in its sediments ranged from 31.72 to 169.32 ng/g dry weight. Similarly, Stefania and colleagues found that Thi Nai Lagoon contained PBDE concentrations as high as 8.93 mg/kg [26].

These data clearly showed that rivers in Vietnam, particularly in Hanoi, faced serious pollution problems due to high EDC concentrations. However, these pollutants did not remain confined to water sources; instead, they spread through interconnected systems, with urban soil being especially vulnerable due to its exposure through urbanisation and agricultural practices. Research confirmed that both urban and agricultural activities required large quantities of river or lake water, thereby enabling EDCs to infiltrate the soil and disrupt its ecological balance [27–29].

3. Impact and Health Effect of EDCs in Vietnam

As mentioned above, EDCs in urban soil primarily originated from industrial activities, and most plastic products contained these pollutants. Therefore, due to extensive industrial development, Vietnam needed to pay close attention to the impact of EDCs on urban soil (Table 2). Although there was no unanimous scientific consensus or conclusive evidence confirming the severe health and environmental impacts of EDCs, many studies suggested a strong correlation between EDCs and environmental, ecological, and possibly societal harm. Moreover, an increasing number of articles reported that the presence of EDCs in the environment could directly or indirectly raise the incidence rates of various types of neoplasms, abnormal reproductive behavior, and feminization at different trophic levels within the food chain [30].

Although most of the above-mentioned research was conducted on animals, these findings remained relevant as reference points to support the potential adverse effects of EDCs on human health [31]. In 2015, the Endocrine Society defined EDCs as exogenous chemicals or mixtures of chemicals capable of interfering with any aspect of hormone action. These compounds could significantly affect reproduction, neurodevelopment, the thyroid and neuroendocrine systems, energy balance regulation, and hormone-sensitive cancers. EDCs could act at various points in the hypothalamic-pituitary-gonadal axis or at the peripheral tissue level. Certain life stages, such as puberty, neonatal development, and fetal life, were particularly susceptible to EDC exposure.

These EDCs were linked to a variety of health issues in humans. Atrazine, an herbicide-derived EDC, was associated with early puberty and an increased risk of breast cancer. Bisphenol A (BPA), found in plastic products, was known to induce neoplastic transformation and premature thelarche. Diethylstilboestrol (DES), a pharmaceutical EDC, was linked to a heightened risk of breast cancer in women. Dichlorodiphenyldichloroethylene (DDE), an EDC found in contaminated water and soil, promoted mammary tumor cell proliferation. Polychlorinated biphenyls (PCBs), originating from contaminated air and food, accumulated in breast adipose tissue and delayed pubertal development. Dioxins, by-products of chlorinated herbicide production and smelting, disrupted breast development and induced epigenetic silencing of key tumor suppressor genes such as TCDD. Pyrethroids, another class of EDCs found in soil, food, and water, were known to delay puberty. Finally, phthalates, which were used in PVC plastics, medical devices, personal care products, and tubing, caused numerous health issues including premature thelarche, delayed pubic hair development, early puberty, and increased breast cell proliferation [32].

Previous studies indicated that Vietnam had experienced elevated hormone levels in women and their breastfeeding children decades after EDC pollution occurred. Professor Teruhiko Kido from Kanazawa University, Japan, who led one such study, identified Vietnam as a hotspot for EDCs compared to other polluted regions worldwide. To assess whether these pollutants could be transferred from mothers to their babies, he conducted a study involving 104 women and their newborns from two different locations: one in northern Vietnam, which was not occupied by the United States Air Force, and Bien Hoa, an industrial city that had stored over 50% of the U.S. military's Agent Orange. There were at least four major leaks in Bien Hoa during the 1970s. The study revealed that both human and environmental samples from the contaminated area still contained high concentrations of EDCs, even after five decades of natural degradation.

Table 2. The impacts and health effects of various EDCs found in the urban soil.

EDC	Source/Origin	Health Effects	Impacts on Human Health	Impacts	References
Atrazine	Herbicide	Early puberty, increased risk of breast cancer	It can cause early puberty and may increase the risk of breast cancer	-	[30]
Bisphenol A (BPA)	Plastic chemicals	Neoplastic transformation, premature larches	It causes neoplastic transformation and can induce premature larches	-	[31]
DES	Medicine	Increased breast cancer risk	Increases the likelihood of women developing breast cancer	-	[30]
DDE	Contaminated water and soil	Promotes cell proliferation and mammary tumour cells	It can harm health by promoting cell proliferation and mammary tumour cell proliferation	Harm to the ecosystem through bioaccumulation in animals	[30]
PCBs	Contaminated air and food	Delay in puberty development	Accumulates in breast adipose tissue, delays puberty	Harm to wildlife through accumulation, delayed effects on the fetal adrenal cortex, and stress response	[34, 35]
Dioxins	The by-product of chlorinated herbicide production and smelting	Delayed breast development, epigenetic silencing of tumour suppressors	Delays breast development and may induce epigenetic silencing of key tumour suppressors	-	[30]
Pyrethroids	Contaminated soil, food, and water	Delayed puberty	Delays puberty upon consumption	Harm to the ecosystem in urban and aquatic environments	[30]
Phthalates	PVC plastic, medical devices, personal care products	Premature larches, delayed pubic hair development, early puberty, increased breast cell proliferation	It can cause early puberty, delayed pubic hair development, and premature larches	-	[32]
Dioxins	Vietnam War Agent Orange	Increased DHEA in babies, persistent EDCs in breast milk and saliva	Evidence shows 3x higher DHEA in babies from polluted areas	Harm to human health, cross-transfer from mother to child through breast milk	[33]
Wildlife Impact	EDC contamination in urban soil	Physiological and sexual behaviour changes, altered sexual differentiation	Alters sexual behaviour and physiology causes irreversible changes	Severe impact on biodiversity, particularly aquatic species	[34, 35]

Although these EDCs primarily resulted from Agent Orange used during the Vietnam War, the findings provided relevant evidence of the long-term impact that EDCs in urban soil could cause. Additionally, researchers tested the EDC and dioxin levels in the breast milk of participating mothers and in non-invasive saliva samples collected from their infants. These tests aimed to measure levels of the hormone Dehydroepiandrosterone (DHEA). The analysis showed that infants in EDC-contaminated areas had three times higher DHEA levels than those from non-contaminated regions. This finding confirmed that EDCs could be transmitted from mothers to babies through both breastfeeding and umbilical cord blood [33].

Beyond human health impacts, EDCs also posed significant threats to other organisms and the broader ecosystem. Research showed that wildlife behavior changed in response to EDC exposure, ranging from subtle physiological or behavioral shifts to permanent alterations in sexual differentiation. These effects were primarily observed in aquatic species at higher trophic levels, though terrestrial species also experienced similar issues. Studies found that various EDCs had different effects on wildlife health [34]. For instance, mixtures of PCBs and Dichlorodiphenyltrichloroethane (DDT) caused adrenocortical hyperplasia in Baltic Sea seals and contributed to bone disorders and reduced bone mineral density in other animals. Furthermore, PCBs were shown to interfere with fetal adrenal cortex development and cause delayed stress responses in affected wildlife [35]. This evidence demonstrated that the presence of EDCs in Vietnam's urban soil not only harmed human health but also threatened biodiversity and ecological balance. Given their persistence, these pollutants could remain in the environment for decades, continuing to endanger both humans and wildlife.

4. Strategies and Efforts to Reduce or Prevent EDCs

To mitigate the harmful effects of EDCs on human health, ecosystems, and biodiversity, a wide range of strategies had been developed and implemented globally over the past few decades. These efforts encompassed regulatory frameworks, scientific research, industry reforms, and international collaborations. In the United States, the American Medical Association (AMA) advocated for stronger regulatory oversight of EDCs. Their recommendations were based on the necessity to address both low-level and high-level exposures, recognizing that even trace amounts of these chemicals—known to cause endocrine disruption—should be considered in public health policy. This comprehensive regulatory approach encouraged agencies to adopt more sensitive testing methods and to account for the cumulative effects of multiple low-dose exposures. Internationally, a significant milestone was reached in 2013 when the United Nations Environment Programme (UNEP) and the World Health Organization (WHO) released a joint report compiling scientific findings on EDCs. The report detailed environmental pathways, biological mechanisms, and associated health risks, and also proposed standardized testing protocols while calling for global policy reforms. This initiative marked a turning point in international awareness and urged national governments to integrate EDC management into their environmental and public health agendas. Within the European Union, strict regulatory measures such as the REACH regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals) were enforced to control the production and use of harmful substances, including EDCs. The EU also established specific scientific criteria to identify EDCs, leading to bans or severe restrictions on their use in consumer products and industrial applications. At the national level, Vietnam had begun to take preliminary steps by enhancing monitoring systems and investing in environmental research. However, the country still required more comprehensive policies and robust regulatory enforcement mechanisms. Public awareness campaigns, improved waste treatment technologies, and mandatory industrial audits could further support efforts to reduce EDC contamination. Table 3 summarizes the strategies and measures aimed at reducing EDC leakage into the environment.

Table 3. Strategies and efforts to reduce EDCs leakage into the environment.

Strategy	Efforts and Actions	Key Players/Regions	Outcomes/Goals
Regulatory Frameworks	- AMA advocating for stronger regulatory oversight of EDCs - Address both low-level and high-level exposures - Encourage sensitive testing methods	United States	- Improve public health policies - Recognize cumulative impact of low-dose exposures
Scientific Research	- UNEP & WHO joint report on EDCs (2013) - Details on environmental pathways, biological mechanisms, and associated health risks - Propose standardized testing protocols	UNEP, WHO	- Global awareness on EDCs - Integration of EDC management into national policies
Industry Reforms	- EU's REACH regulation for controlling EDC production - Specific criteria to identify and restrict EDC use in consumer goods and industrial applications	European Union	- Restrict harmful EDC substances - Control the production and use of EDCs
International Collaborations	- Vietnam improving monitoring systems and investing in research - Public awareness campaigns - Waste treatment technologies - Mandatory industrial audits	Vietnam, Global Initiatives	- Improve national-level enforcement - Reduce EDC contamination

5. Conclusion

Endocrine-disrupting chemicals (EDCs) can be found across multiple sectors of urban areas, making their presence in urban soil increasingly common. Vietnam, in particular, has been identified as a country where EDC contamination is a growing issue due to rapid industrialization and urban development. Historically, one significant contributor to this problem was the use of Agent Orange during the Vietnam War, which introduced persistent organic pollutants into the environment. Today, the ongoing expansion of industrial zones, increased use of chemical-based consumer products, and insufficient wastewater treatment systems have further exacerbated EDC pollution. The impact of EDCs on human health is profound, as these substances interfere with hormone function, potentially leading to reproductive disorders, developmental abnormalities, and increased risks of certain cancers. As urbanization accelerates, concern among Vietnamese citizens about the health and environmental risks posed by EDCs continues to rise. To address this urgent issue, Vietnam must adopt proactive and comprehensive strategies aimed at reducing EDC contamination in urban soil. These measures should include stricter regulatory frameworks for chemical usage, improved waste treatment infrastructure, and national programs to monitor and manage pollutants. Additionally, public awareness campaigns are crucial to inform communities about EDC sources and promote safer practices in agriculture, industry, and daily life. The Vietnamese government holds a critical responsibility to lead these efforts. Taking decisive action now will not only help curb EDC pollution but also safeguard environmental quality, public health, and long-term sustainability for future generations.

Acknowledgements

The authors express their gratitude to Curtin University Malaysia, University of Belgrade (Serbia), Industrial University of Ho Chi Minh City (Vietnam), Sylhet Agricultural University

(Bangladesh), University of Yamanashi (Japan), and Morgan State University, Baltimore, Maryland (USA) for their support and collaboration in making this work possible.

Author Contribution

Upeksha Gayangani Jayasekara, Kadupitige Shashikala Dilrukshi Premarathna, Razman Maznan Salim were responsible for conceptualization, writing, and data collection. Nguyen Thi Thanh Thao, Ferdaus Mohd Altaf Hossai, Rubiyatno, Ocean Thakali, Corry Aina, Ni Putu Sri Wahyuningsih, Nii Amarquaye Commey contributed to the writing and development of the methodology.

Competing Interest

The authors declare that there are no competing interests or conflicts of interest regarding the publication of this review article.

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