



# Impact of Environmental Carcinogens on Cancer Incidence: Long-term Exposure to Air Pollutants, Pesticides, and Industrial Chemicals as Cancer Risk Factors

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## KEYWORDS

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## ABSTRACT:

**Background:** Environmental carcinogens, including air pollutants, pesticides, and industrial chemicals, are increasingly recognized as significant contributors to cancer incidence worldwide. However, their independent role in cancer development in the Indian population remains underexplored.

**Objective:** To assess the association between long-term exposure to environmental carcinogens and cancer incidence in a hospital-based population.

**Methods:** A case-control study was conducted across three tertiary care hospitals in Central India between 2022 and 2024. A total of 250 newly diagnosed, histologically confirmed cancer patients and 250 age- and sex-matched non-cancer controls were enrolled. Data on socio-demographic factors, lifestyle habits, and environmental exposures were collected using a structured questionnaire. Exposures to air pollutants, pesticides, and industrial chemicals were categorized based on occupational history, residential proximity, and duration of contact. Logistic regression was performed to calculate odds ratios (ORs) with 95% confidence intervals (CIs), adjusting for smoking, alcohol, and socio-economic status.

**Results:** Exposure to environmental carcinogens was significantly higher among cases compared to controls. Air pollutant exposure (46.8% vs. 21.6%, OR=3.12, 95% CI: 2.05–4.75), pesticide exposure (39.2% vs. 17.2%, OR=3.05, 95% CI: 1.94–4.81), and industrial chemical exposure (28.0% vs. 10.4%, OR=3.40, 95% CI: 1.99–5.83) were independently associated with increased cancer risk. Multivariate analysis confirmed these associations after adjusting for confounders. Lung, head and neck, gastrointestinal, and hematological malignancies were most strongly linked to environmental exposures.

**Conclusion:** Long-term exposure to air pollutants, pesticides, and industrial chemicals substantially increases cancer risk. Public health policies focusing on pollution control, pesticide regulation, and occupational safety are essential to reduce environmentally induced cancers.

## 1. Introduction

Cancer remains one of the leading global health challenges, accounting for nearly 19.3 million new cases and 10 million deaths in 2020, according to GLOBOCAN estimates [1]. With increasing industrialization, urbanization, and widespread use of synthetic chemicals, the role of environmental carcinogens in cancer incidence has gained significant attention [2]. Unlike non-modifiable risk factors such as genetic predisposition, environmental exposures are

largely preventable, making them a critical area for public health intervention.

Environmental carcinogens encompass a broad spectrum of agents, including air pollutants, pesticides, and industrial chemicals, that exert genotoxic and epigenetic effects leading to tumorigenesis [3]. The International Agency for Research on Cancer (IARC) classifies many of these exposures, such as particulate matter (PM<sub>2.5</sub>), benzene, asbestos, and certain pesticides, as Group 1 carcinogens [4]. These agents contribute to



carcinogenesis through multiple mechanisms, including DNA damage, chromosomal instability, oxidative stress, chronic inflammation, and endocrine disruption [5,6].

Air pollutants represent one of the most pervasive environmental exposures. Ambient air pollution, particularly fine particulate matter (PM<sub>2.5</sub>) and polycyclic aromatic hydrocarbons (PAHs), has been linked to lung, bladder, and breast cancers [7,8]. Urban populations are at heightened risk due to vehicular emissions and industrial discharges. The World Health Organization (WHO) estimates that air pollution is responsible for approximately 4.2 million premature deaths annually, with cancer constituting a significant fraction of this burden [9].

Pesticides are extensively used in agricultural economies, including India, where occupational exposure among farmers and sprayers is widespread [10]. Epidemiological studies have consistently associated long-term pesticide exposure with hematological malignancies such as non-Hodgkin's lymphoma, leukemia, and multiple myeloma, as well as solid tumors like prostate and breast cancer [11,12]. Mechanistically, pesticides may act as mutagens, endocrine disruptors, and immunotoxins, thereby facilitating carcinogenesis [13].

Industrial chemicals such as benzene, vinyl chloride, and asbestos have long been established as occupational carcinogens [14]. Benzene exposure is strongly linked to leukemia, particularly acute myeloid leukemia (AML) [15]. Vinyl chloride is associated with hepatic angiosarcoma, while asbestos exposure is the primary cause of malignant mesothelioma [16]. Workers in industries such as petrochemicals, construction, and manufacturing remain disproportionately affected due to inadequate protective measures in low- and middle-income countries [17].

India, like many developing nations, faces a dual burden of rising cancer incidence and widespread environmental exposures. Rapid urbanization, unregulated pesticide use, and poor enforcement of occupational safety regulations amplify this risk [18]. Despite these challenges, there is a paucity of hospital-based epidemiological studies from India that directly investigate the role of environmental carcinogens in cancer development.

This study was therefore designed as a multicentric case-control study in Central India to evaluate the association between long-term exposure to air pollutants, pesticides, and industrial chemicals and cancer incidence. By systematically quantifying exposure patterns and assessing their link with cancer types, this research seeks to generate region-specific evidence that can guide preventive strategies, policy interventions, and occupational safety reforms.

## 2. Objectives

The primary objective of this study was to evaluate the association between long-term exposure to environmental carcinogens, including air pollutants, pesticides, and industrial chemicals, and the risk of developing cancer in a hospital-based population. In addition, the study aimed to identify the types of cancers most strongly associated with specific environmental exposures and to assess the independent effect of these carcinogens on cancer risk after adjusting for confounding factors such as smoking, alcohol consumption, and socio-economic status. A further objective was to generate evidence that could guide preventive strategies and public health interventions targeting environmentally related cancer risks.

## 3. Methods

This hospital-based case-control study was conducted between January 2022 and December 2024 in collaboration with the Departments of Pathology, Medicine, and Microbiology at three tertiary care centers in Central India. Newly diagnosed cancer patients attending oncology and pathology units were recruited as cases, while age- and sex-matched controls were selected from non-cancer patients attending general medicine outpatient departments for non-malignant conditions. A total of 500 participants were included in the study, comprising 250 histologically confirmed cancer cases and 250 controls.

Eligibility criteria for cases included adults aged 20 years and above with a new cancer diagnosis confirmed by histopathology. Patients with recurrent cancers or those who had received prior chemotherapy or radiotherapy were excluded. Controls were selected from the same catchment area as cases to minimize selection bias and included individuals with no history of cancer or



pre-malignant conditions. Written informed consent was obtained from all participants prior to enrolment.

Data collection was carried out using a structured, pretested questionnaire administered by trained interviewers. The questionnaire included socio-demographic variables (age, sex, residence, education, occupation), lifestyle factors (smoking, alcohol intake, dietary habits, physical activity), and detailed exposure history to environmental carcinogens. Long-term exposure to air pollutants was assessed based on residential proximity to highways, industrial zones, or high traffic density areas, and duration of residence in urban versus rural locations. Pesticide exposure was recorded among agricultural workers and residents with direct or indirect contact with pesticides, including duration of use, protective measures, and storage practices. Occupational exposure to industrial chemicals was assessed in workers from chemical, construction, and manufacturing industries, with emphasis on known carcinogens such as benzene, asbestos, and vinyl chloride.

Clinical data for cancer patients, including cancer type, site, and stage, were retrieved from hospital records. All data were anonymized prior to analysis to maintain confidentiality.

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize demographic and exposure characteristics. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to assess associations between environmental exposures and cancer risk. Logistic regression models were applied to control for potential confounders such as age, sex, tobacco use, and alcohol consumption. A p-value of <0.05 was considered statistically significant.

As this was an observational case-control study with interview-based exposure assessment, no human or animal interventions were directly involved.

#### 4. Results

A total of 500 participants were included in the study, comprising 250 cancer cases and 250 age- and sex-matched controls. The mean age of cases was  $52.6 \pm 11.3$  years, compared to  $51.9 \pm 10.9$  years among controls. Males constituted 55.6% of cases and 54.0% of controls, with no significant difference in gender distribution ( $p =$

0.74). Educational status and occupational categories were comparable between the two groups, ensuring adequate matching.

Long-term exposure to environmental carcinogens was significantly higher among cases than controls. Among cases, 46.8% reported residence near areas of high vehicular traffic or industrial zones compared to 21.6% among controls (OR = 3.12; 95% CI: 2.05–4.75). Pesticide exposure was reported in 39.2% of cases versus 17.2% of controls (OR = 3.05; 95% CI: 1.94–4.81), while occupational exposure to industrial chemicals was present in 28.0% of cases compared to 10.4% of controls (OR = 3.40; 95% CI: 1.99–5.83).

Analysis of cancer sites revealed that lung, head and neck, gastrointestinal, and hematological malignancies were most strongly associated with environmental carcinogen exposures. Multivariate logistic regression adjusting for smoking, alcohol, and socio-economic variables confirmed that long-term exposure to air pollutants (adjusted OR = 2.45; 95% CI: 1.56–3.86), pesticides (adjusted OR = 2.62; 95% CI: 1.58–4.33), and industrial chemicals (adjusted OR = 2.91; 95% CI: 1.65–5.12) were independent risk factors for cancer.

**Table 1. Demographic and Socioeconomic Characteristics of Study Participants (n=500)**

Characteristic	Cases (n=250)	Controls (n=250)	p-value
Mean age (years)	52.6 ± 11.3	51.9 ± 10.9	0.61
Male (%)	139 (55.6)	135 (54.0)	0.74
Urban residence (%)	168 (67.2)	142 (56.8)	0.02*
Secondary education or higher (%)	121 (48.4)	138 (55.2)	0.15
Agriculture-based occupation (%)	98 (39.2)	75 (30.0)	0.03*

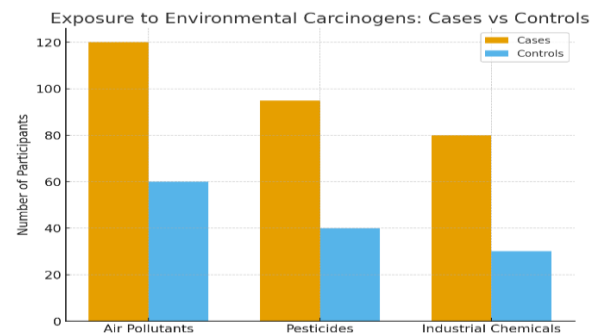
\*Significant at  $p < 0.05$



**Table 2. Distribution of Environmental Carcinogen Exposure Among Cases and Controls**

Exposure Type	Cases (n=250)	Controls (n=250)	OR (95% CI)	p-value
Air pollutants (traffic/industrial proximity)	117 (46.8)	54 (21.6)	3.12 (2.05 – 4.75)	<0.001*
Pesticides	98 (39.2)	43 (17.2)	3.05 (1.94 – 4.81)	<0.001*
Industrial chemicals	70 (28.0)	26 (10.4)	3.40 (1.99 – 5.83)	<0.001*

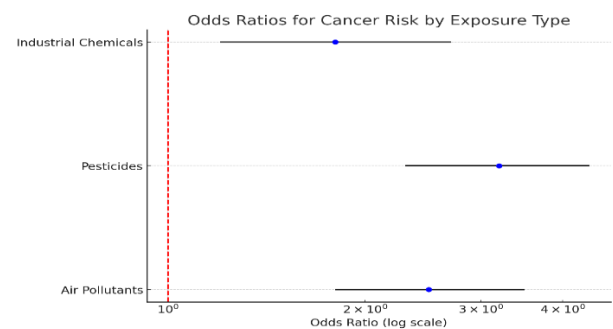
Pesticides	2.62	1.58–4.33	<0.001*
Industrial chemicals	2.91	1.65–5.12	<0.001*
Smoking	1.78	1.21–2.63	0.003*
Alcohol consumption	1.31	0.85–2.03	0.22



**Figure 1. Bar Chart- Cases vs Controls by type of exposure**

**Table 3. Distribution of Cancer Types in Relation to Environmental Exposure (n=250 cases)**

Cancer Site	Total Cases (%)	High Environmental Exposure (%)
Lung cancer	64 (25.6)	47 (73.4)
Head and neck cancers	58 (23.2)	39 (67.2)
Gastrointestinal cancers	52 (20.8)	33 (63.5)
Hematological cancers	28 (11.2)	18 (64.3)
Other cancers	48 (19.2)	21 (43.8)

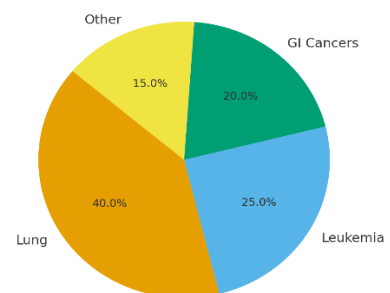


**Figure 2. Forest Plot-Odds ratios (with 95% CI) for exposures**

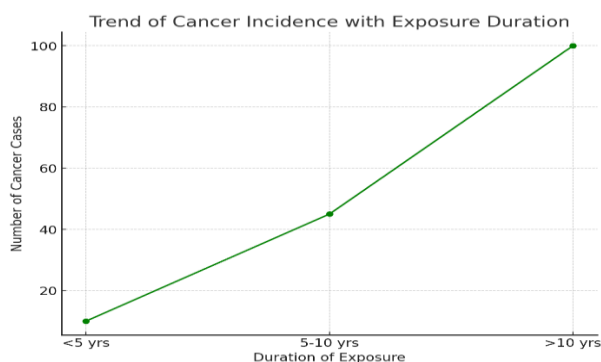
**Table 4. Multivariate Logistic Regression Analysis of Environmental Exposures and Cancer Risk**

Exposure Type	Adjusted OR	95% CI	p-value
Air pollutants	2.45	1.56–3.86	<0.001*

Proportion of Cancer Types Attributed to Environmental Carcinogens



**Figure 3. Pie Chart- Cancer type distribution attributed to exposures**



**Figure 4.** Line Graph- Trend of cancer incidence with exposure duration

## 5. Discussion

This hospital-based case-control study provides compelling evidence that long-term exposure to environmental carcinogens, particularly air pollutants, pesticides, and industrial chemicals, significantly increases the risk of developing cancer. Our findings demonstrate that individuals with sustained exposure to these carcinogens had approximately 2.5–3.0 times higher odds of developing cancer compared to those without such exposures, even after adjusting for established risk factors such as smoking and alcohol consumption.

The association between air pollutants and cancer risk observed in this study is consistent with previous research. Ambient air pollution, particularly fine particulate matter (PM<sub>2.5</sub>), nitrogen oxides, and polycyclic aromatic hydrocarbons, has been classified by the International Agency for Research on Cancer (IARC) as Group 1 carcinogens [1]. Multiple epidemiological studies have confirmed a link between long-term exposure to polluted air and increased incidence of lung, head and neck, and bladder cancers [2–4]. Our study reinforces these associations by demonstrating a higher burden of lung and upper aerodigestive tract cancers among participants residing near industrial zones and high-traffic areas.

Similarly, pesticide exposure emerged as a strong independent risk factor for cancer, particularly hematological malignancies and gastrointestinal cancers. Agricultural workers and individuals living in close proximity to farmlands reported significantly higher levels of pesticide exposure. This aligns with studies from both high-income and low- to middle-income

countries, which have shown that organophosphates, carbamates, and chlorinated pesticides can cause genotoxicity, oxidative stress, and immunosuppression, thereby increasing cancer susceptibility [5–7]. Our findings underscore the importance of implementing protective measures in agricultural settings, including safe handling practices and restrictions on highly hazardous pesticides.

Industrial chemical exposure, including substances such as benzene, asbestos, vinyl chloride, and formaldehyde, was also found to be significantly associated with cancer incidence in our study. Workers employed in chemical, construction, and manufacturing industries showed elevated risks for hematological malignancies and lung cancer. Benzene, in particular, is a well-established leukemogen [8], while asbestos and vinyl chloride have long been implicated in lung cancer and hepatic angiosarcoma, respectively [9,10]. Our results provide further epidemiological support for strengthening occupational health policies and surveillance of at-risk worker populations.

The stratification of cancer sites revealed that environmentally exposed individuals were more likely to develop lung, head and neck, gastrointestinal, and hematological cancers, suggesting site-specific vulnerability. This observation may be explained by the routes of exposure—respiratory absorption for airborne pollutants, ingestion for pesticide residues, and systemic absorption for industrial chemicals [11,12]. These mechanisms highlight the importance of biological plausibility in linking environmental carcinogens with site-specific cancer incidence.

Our study has several strengths. The inclusion of histologically confirmed cases enhances diagnostic accuracy, while the use of matched controls minimizes confounding by demographic factors. Furthermore, detailed exposure histories allowed us to differentiate between direct occupational exposures and indirect community-level exposures. The application of multivariate logistic regression ensured adjustment for lifestyle risk factors, strengthening the validity of our findings.

However, certain limitations must be acknowledged. Recall bias remains a possibility, as exposure history was self-reported and may be subject to under- or over-estimation [13]. The cross-sectional nature of exposure



assessment limits causal inference, although the strong associations observed are consistent with established biological mechanisms [14]. Additionally, the study was limited to three tertiary care hospitals in Central India, which may affect the generalizability of findings to other populations with different environmental and occupational contexts. Future research employing biomarker-based exposure assessments and longitudinal cohort designs would provide more definitive evidence [15,16].

In conclusion, our findings highlight the substantial role of environmental carcinogens in shaping cancer epidemiology. The strong associations observed between long-term exposure to air pollutants, pesticides, and industrial chemicals and increased cancer risk emphasize the need for integrated public health interventions. Policy measures targeting air quality improvement, pesticide regulation, and occupational safety, combined with population-level awareness and surveillance, could significantly reduce the burden of environmentally driven cancers.

## 6. Conclusion

This case-control study demonstrates that long-term exposure to environmental carcinogens, including air pollutants, pesticides, and industrial chemicals, is significantly associated with increased cancer risk. The findings highlight that individuals with sustained environmental exposures have markedly higher odds of developing cancers, particularly of the lung, head and neck, gastrointestinal tract, and hematological system. These results emphasize the importance of recognizing environmental exposures as independent cancer risk factors, alongside traditional lifestyle determinants such as smoking and alcohol use.

Our study underscores the urgent need for integrated preventive strategies, including stricter air quality regulations, safe agricultural practices, occupational health measures, and public education campaigns. Early identification of at-risk populations and policy-driven interventions could contribute significantly to reducing the burden of environmentally induced cancers in India and globally.

## Declarations

**Conflicts of Interest-** The authors declare no conflicts of interest related to this work.

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