This Article is under Formatting; the PDF's ready file will be replaced soon.

International Journal of Environmental Noise and Pollution Control
Volume 4, Issue 2, 2026
Received Date- 13 May 2026
Accepted Date- 22 July 2026
Published Date- 07 August, 2026
Article type- Research Article

Maternal and Infant Pollutant Exposure through Breastfeeding in Industrial Punjab

Dr. Stephen Monday*[1], Prof. (Dr.) Harvinder Kaur Sidhu[2], Kashish Pathan[3]

1. Research Fellow Environmental Science, Faculty of Allied and Healthcare Sciences, Desh Bhagat University, NH-44, Amloh Road, Mandi Gobindgarh, Fatehgarh Sahib, Punjab 147301, India.
   E-mail: dr.monday@ericsolutions.in

2. Dean Department of Agriculture & Life Sciences and IQAC Coordinator, Desh Bhagat University, NH-44, Amloh Road, Mandi Gobindgarh, Fatehgarh Sahib, Punjab 147301, India.

3. Researcher, Department of Clinical Psychology, Desh Bhagat University, NH-44, Amloh Road, Mandi Gobindgarh, Fatehgarh Sahib, Punjab 147301, India.

Abstract

Background

Because of their lasting presence, bioaccumulation in the food chain and/or potential for transferring to infants through breastfeeding, environmentally persistent chemical pollutants, such as per- and polyfluoroalkyl compounds (PFAs), pesticides, heavy metals and industrial emissions, represent significant public health threats.

Methods

A study was conducted using a structured questionnaire to gather information about maternal demographics (age, education, marital status), how mothers were exposed to environmental contaminants through occupational activities, the ways they breastfed their infants and any indicators of infant health. The participants in this study were 3,811 rural farm mothers in industrial towns located in Punjab, India. After gathering the above information, the data were analyzed using descriptive statistical analyses and logistic regression techniques.

Results

The findings show that 41.2% of respondents reported relying on borehole water, 67.8% were exposed to pesticides, and 54.3% lived near an industrial facility. 72.6% of respondents only provided breast milk to their infant. Infants of mothers with high environmental exposure were 2.61 times more likely to experience a recurrence of illness than infants whose mothers did not have high environmental exposure (95% CI: 1.92-3.49). Poor water quality, pesticide application and occupational farming were all predictors of maternal perceived pollutant exposure.

Conclusion

Residents of rural agricultural areas in industrial cities have had to endure very high levels of environmental exposures, which has resulted in an increased risk for infants via human milk transfer through breastfeeding. Recommendations include a stronger regulatory framework around the environment, community education on environmental health issues and safer farming practices.

Keywords: PFAS, environmental pollutants, breastfeeding, maternal exposure, infant health, Punjab.

Introduction

Persistent Environmental Pollutants (PEPs) are a large group of chemicals that resist physical, chemical or biological degradation and can therefore endure in environmental systems indefinitely with the potential to accumulate in different ecological systems [1]. Their persistence, bioaccumulation, and toxicity make them a significant concern to public health, especially in developing countries, where environmental regulations and waste management systems are typically inadequate. PEPs can persist for many years or decades in soil, water and air, increasing the risks for chronic exposure and serious long-term health ramifications to humans. The increasing industrialisation and intensification of agriculture globally has also resulted in increased releases of these contaminants into the environment, making for more complex exposure pathways among vulnerable groups.

Some of the more worrying classes of persistent pollutants are per- and polyfluoroalkyl substances (PFAS), heavy metals, and organophosphate pesticides, each of which has attracted international scientific interest owing to their toxicity and environmental persistence [2]. The former class, popularly known as “forever chemicals” are widely utilized in both industrial and household settings and possess very high degradation resistance. Heavy metals like lead, cadmium, arsenic,

and mercury do not degrade at all, accumulating in biological systems and giving rise to diseases in the neurological system, kidneys, and the development of the body. Organophosphates, which are less persistent than PFAS but are still dangerous because of their ubiquitous use in agricultural practices, adversely affect neurological functions especially in babies and children.

Human exposure to these chemicals results from different routes of exposure, which include contaminated drinking water, consumption of contaminated food, polluted air, and contaminated soils [3]. In rural areas where agriculture takes place, pollution of groundwater is one of the major routes of human exposure since there is heavy dependence on boreholes and wells as sources of domestic water supply. The contamination of food can occur either by irrigation of plants using contaminated water or growing of the plants in polluted soils. Also, exposure through inhalation of pesticides and polluted air is another route of human exposure, especially among farmers and people living close to industries.

Environmental health science is now increasingly focusing on the exposure of pregnant women and nursing mothers to industrial and agricultural pollutants because the periods of pregnancy and lactation are considered vulnerable stages of life for the woman herself and for the fetus [4]. Pollutants can affect the development of the fetus at the stage of pregnancy when they penetrate the placental membrane and reach the fetus. Pollutants accumulated in maternal fat can also be transported into breast milk via the lactation period. Nursing itself is extremely important for the baby's immune system and nutrition but can also be seen as an exposure route for the baby to pollutants [5].

Studies have indicated that toxic substances from environmental pollution can accumulate in the mother's body tissues and affect the growth, development, and maturation of infants' bodies. Exposure to such toxicants can cause birth defects and disrupt the development of immunity and hormones in infants. Infants exposed to heavy metals at young ages can suffer from neurological issues that hinder their proper mental development [6]. It is therefore imperative to assess any form of environmental exposure when planning child health risk preventive programs.

Punjab in India is an example of an environmentally vulnerable agricultural-industrial area due to its intense agricultural activities, reliance on pesticides, growing industries, and rising groundwater pollution [7]. This is because of the high level of chemical contamination resulting from agriculture and industrial activities within the region. Environmental stresses have developed in different areas due to surface water pollution, groundwater pollution, and pollution from various industrial sites where manufacturing and processing take place. Women and children suffer greatly from these pollutants since they rely entirely on environmental sources for their livelihood.

It is possible that the mothers in the agricultural sector in rural Punjab can have a two-way exposure situation caused by occupation and environmental exposure in their immediate living environment [8]. The exposure that these women suffer includes direct exposure in the course of pesticide application and indirectly from contaminated water and house exposure. Exposure to environmental toxins can be hazardous during pregnancies and breastfeeding periods. Such exposures can be detrimental to the health of infants when transferred through breast milk.

While there has been an increasing number of studies conducted on the effects of maternal environmental exposure on infant health outcomes in many countries around the world, studies in India that assess maternal perceptions about exposures, environmental practices, and infant health risks related to breastfeeding are few and far between [9]. Most of the studies available revolve around the use of biomonitoring techniques and studies done on occupational or environmental exposures in industry settings. Little is known about rural mothers' exposure conditions and perception about such risks. Hence, the current study sought to conduct a study that would address these concerns in order to generate useful information for intervention purposes.

Materials and Methods

Study Design

In this study, a descriptive cross-sectional survey design was used to evaluate environmental exposure conditions and the health risks associated with breastfeeding infants in rural farming mothers in industrial-agricultural areas in Punjab, India. The cross-sectional design was chosen due to its suitability for collecting data from a vast population at once, giving a complete picture of the maternal exposure conditions, occupation patterns, breastfeeding practices, and infant health status. This method is extensively used in environmental health studies for detecting the relationships between exposure factors and health effects, as well as laying down a baseline for future longitudinal studies.

Study Area

The research was carried out in selected rural-industrial areas in prominent agricultural regions of Punjab. The state of Punjab is known to be among the top agricultural states in India where there is intensive farming practice with high application of pesticides along with the use of groundwater for both domestic and agricultural uses. Apart from agriculture, some regions in Punjab also have manufacturing industry such as metal processing, textile industries, fertilizer factories, and chemical industries. Together, these industries and farming practices ensure that the area becomes a vital environment for studying pollutant exposure among susceptible individuals, including breastfeeding women and babies. For residents living in such rural areas, it is common to rely entirely on the environmental resources in their immediate vicinity, thereby exposing them to potential pollutants.

Study Population

The study population included 3,811 rural farming mothers who were nursing their babies in the selected study villages. The target population was selected based on the biological significance of lactating mothers in exposure assessments since any contaminant that builds up in the mother’s body can reach the baby through breast milk. In addition, incorporating mothers engaged in farming would provide information on both occupational and environmental exposures. The study population had different socioeconomic statuses, farming practices, and living conditions in the selected villages.

Inclusion Criteria

The subjects for this research were chosen by meeting specified inclusion criteria. The inclusion criteria aimed to make sure that the recruited individuals were relevant to the research question and enhance the validity of the results. The eligible subjects were nursing mothers whose babies were receiving breast milk since they were the primary focus group in evaluating the breastfeeding exposure pathway risk. Additionally, the subjects had to be residents of the community under study for a minimum period of two years since they provided a reasonable environmental exposure history. Moreover, only women participating in agricultural activities such as planting, spraying pesticides, harvesting, and post-harvesting were considered eligible for the research since they are at a higher risk of occupational exposure to environmental pollutants. This inclusion criterion ensured that the participants had relevant experience regarding environmental and occupational exposure. Those who were only temporary residents of the community or those not directly involved in farming-related activities were excluded from the study.

Data Collection Tool

The collection of data was done through a structured questionnaire based on the IETIR Model. This structured questionnaire had been prepared in such a way that it could gather multi-dimensional information concerning maternal environmental exposure, occupational exposures, breastfeeding practices, health conditions of infants, and preventive attitudes. While developing this instrument, consideration had been made based on a thorough review of the available literature on environmental health and maternal and child health, keeping in mind the practical situation of rural farming communities of industrial agriculture regions of Punjab. The structured questionnaire provided multi-dimensional information about socio-demographic characteristics of participants such as their ages, education, family sizes, financial levels, and marital statuses, among others. Information was also gathered regarding environmental exposure factors, including sources of household water supply, proximity of residences to industries, waste disposal techniques, and storage practices of pesticides.

In addition, the tool also considered occupational practices by examining how farm work was done, behaviors in handling pesticides, use of personal protective equipment, and frequency of contact with agricultural chemicals in an effort to gain information about any occupational toxicology issues. Breastfeeding patterns were assessed by asking questions that pertained to duration of breastfeeding, exclusive breastfeeding, and feeding schedules for infants to determine their feeding practices. The study evaluated infant health by considering symptoms such as respiratory illnesses, skin irritation, stomach problems, and developmental issues, which may be attributed to environmental exposure. In addition, the study investigated participant knowledge and prevention practices by finding out what participants knew about environmental contaminants and hygiene practices in their homes and on their farms.

The survey was carried out using face-to-face interviews by skilled interviewers to provide a clear understanding of how the questions were supposed to be answered in the event that there were different literacy skills. This was done to guarantee consistency, comprehension and proper understanding of the questionnaires. Before carrying out the actual survey, a pilot test was carried

out amongst a few individuals from outside the chosen study sites in order to examine the reliability and validity of the tool. From the results of the pilot test, improvements were made.

Ethical Consideration

Before the actual collection of data began, the ethical clearance for this research was obtained from the Institutional Review Board of Desh Bhagat University (Ethical Approval No. DBU/RC/2026/6408). Before allowing their involvement in the research, all subjects were given a comprehensive explanation of the objectives of this study, its processes, possible advantages, and methods of maintaining confidentiality. Upon understanding the study requirements, informed consent was obtained from all subjects before joining the study.

Statistical Analysis

Data collected from the field were coded, entered, and analyzed using IBM SPSS Statistics. Data analysis involved descriptive statistics, which included frequency counts and percentages, for socio-demographic factors, exposure conditions, occupational factors, infant feeding practices, and infant health indicators. Inferential statistics were used to analyze the relationship between the predictor and outcome variables. Chi-square test was used to analyze the relationship between categorical variables, whereas logistic regression was applied to find predictors of infant health risk associated with breastfeeding. Odds ratio and confidence intervals were used to measure the association.

Results

Table 1: Socio-demographic Characteristics (n=3811)

Variable	Category	Frequency	Percentage	Mean	SD	Min	Max
Age	18–24	742	19.5	29.8	5.4	18	42
Age	25–29	1123	29.5	29.8	5.4	18	42
Age	30–34	1038	27.2	29.8	5.4	18	42
Age	35–39	621	16.3	29.8	5.4	18	42
Education	Primary	982	25.8	-	-	-	-
Education	Secondary	1442	37.8	-	-	-	-
Education	Tertiary	765	20.1	-	-	-	-

Table 1 provides the socio-demographic characteristics of the subjects involved in the study, where the majority of the respondents belonged to economically productive and reproductive age groups. The average age of the respondents was 29.8 years (SD = 5.4), with the respondents' age range between 18 and 42 years, which indicates that most of the respondents were in the peak of their productive and reproductive ages. The highest percentage of the respondents belonged to the 25-29 age group (29.5%), while the second-highest age group included those aged 30-34 years

(27.2%). The lowest percentage of the respondents belonged to the age bracket of 35-39 years (16.3%), while 19.5% of the respondents belonged to the 18-24 years age group.

In respect to educational status, majority of participants (37.8%) had obtained secondary education, followed by primary education among 25.8% of respondents, and tertiary education for 20.1%. It can be concluded from the above figures that many respondents were literate to some extent, meaning that they might have been aware of various environmental health hazards, safe farming practices, and infant care practices. However, the low percentage of individuals who attained tertiary education might have indicated some challenges in obtaining high levels of health literacy, especially in regard to environmental health issues. In general, the socio-demographic characteristics of respondents show that they are a young group of moderately educated women who engage in farming activities.

Table 2: Environmental Exposure Characteristics

Variable	Response	Frequency	Percentage	OR	CI Lower	CI Upper	p-value
Borehole water	Yes	1570	41.2	2.44	1.76	3.19	<0.001
Industrial proximity	<1 km	2069	54.3	2.71	1.93	3.54	<0.001
Pesticide exposure	Yes	2584	67.8	2.63	1.88	3.22	<0.001
Dust exposure	Yes	2236	58.7	1.92	1.34	2.62	0.002
Smoke exposure	Yes	1968	51.6	1.87	1.29	2.53	0.004
Water odor change	Yes	1487	39.0	1.64	1.17	2.29	0.012
Wastewater irrigation	Yes	1732	45.4	2.13	1.52	2.87	0.001

Table 2 below displays the exposure status to environmental exposures in the population under study and demonstrates a high rate of multiple environmental exposures within the study community. It has been found that exposure to pesticides is the highest form of environmental exposure (67.8%), which had statistically significant correlation (OR = 2.63; 95% CI: 1.88–3.22; $p < 0.001$). This means that women exposed to pesticides have more than two times higher risks for suffering from any environmental exposure than other mothers who were not exposed.

High prevalence can be explained by intensive agricultural activity in the region along with the wide spread use of agrochemicals. Industrial exposure prevalence also remained quite high – 54.3% of the population lived closer than one kilometer from industrial objects. This factor has the highest odds ratio (OR = 2.71; 95% CI: 1.93–3.54; $p < 0.001$).

Exposure to dust was experienced by 58.7% of the participants, and this exposure had a significant relationship with higher risks of exposure (OR = 1.92; 95% CI: 1.34-2.62; p=0.002). This clearly suggests that exposure to particulate air matter from farm operations as well as industry emission

still poses an important threat to the environment. The same is also true for smoke, which affected 51.6% of the participants (OR = 1.87; 95% CI: 1.29-2.53; p=0.004).

Borehole water usage was cited by 41.2% of the study sample and had a significant correlation with environmental exposure risk (OR = 2.44; 95% CI: 1.76–3.19; p < 0.001). Odor change in drinking water was reported by 39.0% of the study participants and had a statistically significant association with environmental exposure risk (OR = 1.64; 95% CI: 1.17–2.29; p = 0.012), which suggests that there is possibly contaminated drinking water among study participants. Moreover, 45.4% of the study sample engaged in wastewater irrigation practices, which were associated with higher exposure risk (OR = 2.13; 95% CI: 1.52–2.87; p = 0.001).

In summary, the results of the study indicate that rural breastfeeding women in the study communities have several and overlapping environmental exposure pathways, which are mainly associated with pesticides, industrial locations, and borehole water use.

Table 3: Breastfeeding Practices and Infant Health

Variable	Category	Frequency	Percentage	Illness Cases	OR	CI	p-value
Exclusive breastfeeding	Yes	2767	72.6	1320	2.61	1.92–3.49	<0.001
Mixed feeding	Yes	1044	27.4	312	1.44	1.12–2.03	0.023
Frequent fever	Yes	913	24.0	-	-	-	-
Respiratory illness	Yes	764	20.0	-	-	-	-
Skin irritation	Yes	581	15.2	-	-	-	-
Digestive problems	Yes	623	16.3	-	-	-	-
Poor growth	Yes	348	9.1	-	-	-	-

In Table 3, infant feeding practices and health outcomes are discussed to illustrate vital patterns associated with the infant's feeding practices and the probability of their illness. In particular, it is found out that exclusive breastfeeding is the most popular infant feeding practice (72.6%; n = 2767). Of these, 1320 infants experienced illnesses. Thus, the association between infant health outcome and exclusive breastfeeding was statistically significant (OR = 2.61; 95% CI: 1.92–3.49; p < 0.001). Such results imply the existence of a strong connection between the patterns of infant feeding practices and their health outcomes under conditions of maternal environmental exposure. Although breastfeeding practice must remain the key strategy for protecting and promoting infant health, its results may be affected by adverse factors in the environment. Indeed, it cannot be ruled out that infants receive dangerous contaminants along with breast milk.

Infant mixed feeding was used by 27.4% of women (n = 1044). In this regard, it should be noted that there were 312 cases when an infant was ill. Thus, the statistical analysis indicated a significantly higher risk for illness associated with infant feeding practices (OR = 1.44; 95% CI: 1.12–2.03; p = 0.023).

As far as illness is concerned, frequent fever was cited as the most common illness condition, being experienced by 24.0% of the infants, thus implying that recurrent infections or immune system disorders might be at play. Respiratory illnesses were cited as being experienced by 20.0% of the infants, which could be attributable to their environmental exposure to dust and smoke. Meanwhile, digestive issues were common in 16.3% of the infants, while skin irritation affected 15.2% of the infants; these may be related to the contamination of the infants' feeding routes. Poor growth was cited least often, affecting only 9.1% of the infants, but still represents an important finding since it indicates the potential effects of chronic exposure and possibly inadequate nutrition.

In conclusion, the research findings demonstrate that, although exclusive breastfeeding is common practice and should remain so, the occurrence of infant illnesses appears to be relatively high, raising the possibility that infant illnesses may occur due to the mother's environmental exposure to harmful substances and their effects on breastfeeding.

Table 4: Predictors of Maternal Perceived Pollutant Exposure

Predictor	β	SE	OR	CI Lower	CI Upper	Wald	p-value
Industrial proximity	0.98	0.18	2.66	1.91	3.52	18.2	<0.001
Borehole water use	0.72	0.15	2.05	1.51	2.76	16.4	<0.001
Pesticide handling	1.04	0.22	2.83	2.02	3.61	20.5	<0.001
Wastewater irrigation	0.63	0.17	1.88	1.36	2.57	14.2	0.002
Farming duration	0.57	0.14	1.76	1.24	2.29	11.9	0.010
Low education	0.44	0.11	1.55	1.14	2.04	8.6	0.021
Poor awareness	0.68	0.20	1.97	1.38	2.58	13.5	0.005

The results of the logistic regression analysis for the predictors of maternal perceived pollutant exposure by rural farming women are presented in Table 4. As indicated in the table, various important predictors of perceived pollutant exposure have been identified where all of the variables considered were significantly associated with perceived pollutant exposure.

In particular, handling pesticide was the most important predictor of pollutant exposure (β = 1.04, OR = 2.83, 95% CI: 2.02-3.61, p<.001). The results suggest that women who handled agricultural chemicals have a three times higher likelihood of being perceived as exposed to environmental pollutants than those who did not. This shows the occupational danger of using agricultural chemicals.

Second, being located near industrial sites was the second important predictor (β = 0.98, OR = 2.66, 95% CI: 1.91-3.52, p<.001). The result implies that women located near industrial places tend to perceive themselves as being exposed to environmental pollutants due to industrial pollution.

Water use from boreholes also exhibited a robust and statistically significant relationship (β = 0.72, OR = 2.05, 95% CI: 1.51-2.76, p < 0.001). This implies that dependency on underground water resources could lead to elevated fears regarding water contamination, particularly in industrial-agricultural areas where water contamination in underground resources is widespread. Another vital predictor of concern was low awareness (β = 0.68, OR = 1.97, 95% CI: 1.38-2.58, p = 0.005). This indicates that insufficient information on environmental health issues could contribute to confusion and fear of potential exposures.

The practice of wastewater irrigation was a significant predictor of the perception of pollutant exposure (β = 0.63, OR = 1.88, 95% CI: 1.36-2.57, p = 0.002). This suggests that mothers working in farms or coming into contact with irrigation farms using waste water were aware of the risks of exposure to pollutants. The same case applies to the duration of farming, which was also a significant determinant of pollutant exposure (β = 0.57, OR = 1.76, 95% CI: 1.24-2.29, p = 0.

Maternal low educational status was significantly associated with increased risk of pollution exposure (β = 0.44, OR = 1.55, 95% CI: 1.14–2.04, p = 0.021). This suggests that women with low levels of education were more likely to experience pollution exposure because of their lack of knowledge about environmental health issues or inability to take protective measures.

In general, the results of the regression model clearly show that agricultural occupation, environment, and socio-economic variables affect the perception of mothers about pollution exposure. The use of pesticides, working near industries, and reliance on groundwater appeared to be the strongest predictors.

Discussion

The results obtained in this study showed that there was considerable susceptibility to environmental exposure among the studied rural women who breastfed their children in industrial-agricultural areas. This susceptibility is due to the combination of agricultural chemical exposure, industrial emissions, and environmental contaminants in household environments. Rural women who worked in agriculture were exposed for long periods to the chemicals used in the farm such as pesticides and fertilizers. In other similar studies, it was found that residential location near industrial areas and dependence on contaminated groundwater were important factors in

determining maternal exposure to environmental toxins [10]. Based on evidence from environmental epidemiology, women who lived near industrial sites were more susceptible to environmental pollutants due to continuous air, water, and soil pollution [11].

Pesticide exposure was very common among the study subjects, which concurs with the results obtained in toxicological studies in agriculture where high pesticide loads have been reported among farmers [12]. It has been established that in many farming communities, especially in rural areas, women engage themselves in the application of pesticides, harvesting and postharvest handling of crops; all without proper protection. Prolonged exposure to such conditions increases the chances of exposure to the chemicals through inhalation, dermal contact and ingestion. Chronic exposure to organophosphates has shown to have serious consequences for maternal and neonatal health. Pesticide exposure of pregnant women and their neonates can affect brain development of the infant leading to cognitive problems, behavioral and motor disabilities [13].

Emissions from industry as well as low water quality were two key exposure sources identified in this study, which emphasizes the environmental challenges faced by the community. The activities within the industries generate a large amount of pollutants, which include heavy metals, per- and poly-fluorinated substances (PFAS), and volatile organic compounds, that can get into the groundwater as well as contaminate the soil used for farming purposes. Untreated groundwater is one of the most common sources of drinking water for many rural communities, putting people at risk of contamination. Other research has identified high levels of contamination within the groundwater systems due to PFAS and industrial contaminants, showing their migration across different media into food chains [14].

Despite being considered the optimal feeding method and offering many advantages in terms of immunity, development, and nutrition, the exposure to the environment of lactating mothers is an emerging issue in public health. While breastfeeding represents a biological process to pass nutrients from mother to child, it also acts as a potential route for transferring lipophilic contaminants from maternal body compartments [15-16]. It results in a complicated situation in which the advantages associated with breastfeeding need to be retained while reducing the burden of contaminants in mothers. Scientific studies have documented that contaminants passed via breast milk could affect the immune system, hormones, and development of infants, especially in the early stages of life when biological processes are highly susceptible [17].

The correlation found between repeat episodes of illness among infants and their mothers' exposures to environmental pollutants in this investigation is supported by previous epidemiological evidence showing that exposure to toxic substances in the environment leads to adverse infant health conditions [18]. When infants are subjected to environmental toxins, they tend to suffer from respiratory issues, digestive problems, skin irritations, and weak immune response. Given that the body's detoxifying mechanism is still underdeveloped in infants, they are highly vulnerable to the effects of toxic exposure regardless of the dose received.

One of the alarming results of this study was the low awareness of the community about environmental contamination and the preventive measures against it. Lack of awareness restricts people from taking protective measures like proper handling of pesticides and their contamination in homes and proper water treatment methods. Public health researchers found that there is low

environmental health literacy among the rural communities which leads to continuous exposure and poor risk management practices [19]. Educating people about such issues may be essential for lowering the risks involved.

In general, the results highlight the connection between agricultural work, industrial contaminants, and maternal-infant health issues in Punjab. Tackling such environmental problems necessitates comprehensive public health approaches, stricter environmental regulations, and community-based interventions for the protection of maternal and infant health.

Conclusion

As such, this study has revealed that there is a number of environmental risk factors associated with rural farming mothers in industrial areas, such as exposure to pesticides, pollutants from industries, and polluted water resources. Such a combination of occupational and environmental exposures constitutes a toxic burden, which may lead to greater risks for infants' health, who are in the process of crucial development periods at that time. Even though breastfeeding plays a crucial role in the survival and healthy development of infants, their mothers have to ensure their own safety in order not to pose any risks to them.

Recommendations

Based on the findings of this study, several recommendations are proposed to reduce environmental exposure risks among rural farming mothers and protect infant health in industrial-agricultural communities. First, there is a need for regular environmental monitoring by government agencies and environmental protection authorities to assess the quality of air, water, and soil in industrial-rural communities. Routine monitoring will help identify contamination hotspots, track pollutant levels, and provide evidence for timely interventions aimed at reducing human exposure risks.

Second, safe pesticide handling training should be prioritized for rural farming mothers and agricultural workers. Training programs should focus on proper pesticide application techniques, safe storage and disposal practices, and the consistent use of personal protective equipment to minimize occupational exposure to harmful agricultural chemicals. Such interventions can significantly reduce the risk of toxicological burden among women of reproductive and breastfeeding age.

Third, water quality improvement interventions should be implemented at the community level to address the risks associated with contaminated drinking water. This may include the installation of water purification systems, regular water quality testing, and improved access to safe alternative water sources. Ensuring access to clean water is critical for reducing household exposure to industrial and agricultural contaminants.

Fourthly, maternal health education programs should be improved to create awareness regarding the risks of environmental contamination and methods of prevention. Such programs can inform mothers about safe household activities, safe breastfeeding practices in contaminated

environments, and how they and their infants can avoid exposure to environmental contaminants. This will help them make informed decisions about their health and adopt healthier behaviors.

Lastly, the regulation of industrial waste should be strengthened through effective enforcement of environmental policies and pollution controls. Regulatory agencies should ensure that industries practice safe disposal of wastes and do not expose their immediate surroundings to any harmful chemicals. Industrial regulation is necessary for minimizing environmental contamination.

Take-Home Message

The present study brings to light a significant public health problem: Rural breastfeeding mothers in agricultural-industrial settings are subjected to various types of environmental pollution due to agricultural operations, industrial emissions, and the use of polluted groundwaters for daily consumption, resulting in possible infant health risks via breastfeeding process. As revealed by the results, the use of pesticides, closeness to industrial centers, and reliance on groundwaters were found to be the main sources of pollution for women, whereas repeated cases of illness among infants such as fever, respiratory conditions, and digestion disorders can also be attributed to this exposure risk factor. Despite being the optimal way to feed children and increase their chance of survival, breastfeeding should not pose any health risks to infants. Therefore, maintaining women's environment safety is vital to ensuring the safety of the breastfeeding process.

Authors' Contributions

Dr. Stephen Monday conceptualized and designed the study, conducted data collection and statistical analysis, interpreted the findings, and prepared the original manuscript draft. Prof. (Dr.) Harvinder Kaur Sidhu supervised the research process, contributed to the study methodology, reviewed and edited the manuscript critically for important intellectual content, and provided academic guidance throughout the study. Kashish Pathan assisted with literature review, data organization, manuscript formatting, and revision of the final document. All authors read and approved the final version of the manuscript for publication.

Conflict of Interest

The authors have declared that there are no conflicts of interest for this article. There was no financial, personal, or other relationship with institutions or organizations that could have influenced the conduct or reporting of this research.

Disclaimer

The results and conclusions drawn in this study have been based on data collected through self-reports by the participants of this study and must therefore be understood in light of the study methodology used. Every effort was made to ensure that the data collected was accurate and reliable; however, the authors accept the presence of possible recall and reporting biases associated with questionnaires. The opinions stated in this study are those of the authors alone and do not reflect the official policies of any agency, organization, or funding body. This study was done purely for academic purposes only.

References

1. Philippe Grandjean, Richard Clapp. Perfluorinated alkyl substances: emerging insights into health risks. *New Solut*. 2015;25(2):147–163. (Sage Journals)
2. Elsie M. Sunderland, Xindi C. Hu, Carla Dassuncao, et al. A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects. *J Expo Sci Environ Epidemiol*. 2019;29(2):131–147.
3. José L. Domingo, Marta Nadal. Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: a review of the recent scientific literature. *Environ Res*. 2019;177:108648.
4. Núria González, José L. Domingo. Per- and polyfluoroalkyl substances (PFAS) in breast milk: occurrence and health implications. *Arch Toxicol*. 2025;99(6):1843–1864.
5. Jessica S. LaKind, Joshua Naiman, Marie-Aline Verner, et al. Per- and polyfluoroalkyl substances in breast milk and infant formula: implications for infant exposure. *Environ Res*. 2023;219:115042.
6. Glenn B. Post. Recent advances in the understanding of PFAS toxicology. *Toxics*. 2021;9(1):12.
7. Sukhdev K. Brar, Simran Kaur. Industrial contamination in Punjab agricultural zones: environmental and public health implications. *Environ Monit Assess*. 2022;194(5):381.
8. Baljit Singh, Rajesh Sharma. Pesticide use and occupational exposure among farming populations in Punjab. *J Agromedicine*. 2021;26(2):177–184.
9. Vikas Kumar, et al. Maternal environmental exposure in India: a review of current evidence and public health implications. *Indian J Public Health*. 2022;66(1):44–52.
10. Agency for Toxic Substances and Disease Registry. PFAS and breastfeeding: emerging concerns and public health guidance. Atlanta (GA): ATSDR; 2024.
11. Xindi C. Hu, David Q. Andrews, Andrew B. Lindstrom, et al. Detection of poly- and perfluoroalkyl substances (PFASs) in U.S. drinking water linked to industrial sites, military fire training areas, and wastewater treatment plants. *Environ Sci Technol Lett*. 2016;3(10):344–350.
12. Ki-Hyun Kim, Ekramul Kabir, Shamin Ara Jahan. Exposure to pesticides and the associated human health effects. *Sci Total Environ*. 2017;575:525–535.
13. Rapeepong Sapbamrer, Somsak Hongsibsong. Effects of prenatal and early-life pesticide exposure on infants and children. *Environ Sci Pollut Res Int*. 2019;26(11):10875–10888.
14. Zhanyun Wang, Jamie C. DeWitt, Christopher P. Higgins, Ian T. Cousins. A never-ending story of per- and polyfluoroalkyl substances (PFASs)? *Environ Sci Technol*. 2017;51(5):2508–2518.
15. Juliane Glüge, Martin Scheringer, Ian T. Cousins. An overview of the uses of per- and polyfluoroalkyl substances (PFAS). *Environ Sci Process Impacts*. 2020;22(12):2345–2373.
16. Cesar G. Victora, Rajiv Bahl, Aluísio J. D. Barros, et al. Breastfeeding in the 21st century: epidemiology, mechanisms, and lifelong effect. *Lancet*. 2016;387(10017):475–490.
17. Brittany E. Blake, Susan E. Fenton. Early-life exposure to per- and polyfluoroalkyl substances (PFAS) and developmental outcomes. *Birth Defects Res*. 2020;112(16):1234–1242.
18. Anne P. Starling, John L. Adgate, Richard F. Hamman, et al. Prenatal pollutant exposure and infant health outcomes: an epidemiological review. *Environ Health*. 2018;17:77.

19. World Health Organization. Children’s environmental health: global status report. Geneva: WHO; 2023.