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The Impact of Indian Agriculture on Pollution and Public Health: A Review

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ABSTRACT
While Indian agriculture is critical to national food security and economic stability, it has also been identified as a major contributor to environmental degradation and poor public health. This study examines the intricate relationship between contemporary agricultural practices and pollution in India, with a particular focus on air, water, and soil contamination. The widespread burning of crop leftovers, the excessive use of chemical fertilizers and pesticides, and inadequate irrigation techniques are all significant contributors. Crop residue burning causes seasonal surges in particulate matter, leading to increased air pollution across the Indo-Gangetic Plain and resulting in tens of thousands of premature deaths annually. Pesticide and nitrate runoff into bodies of water has caused a variety of chronic health problems, including respiratory ailments, hormonal issues, and cancer. This article highlights the disproportionate impact on vulnerable populations, particularly children, women, and rural farming communities, by employing a multidisciplinary approach that incorporates satellite data, epidemiological studies, and policy analysis. It also assesses the efficacy of existing mitigating techniques, such as zero-tillage technology, stubble-burning prohibitions, and organic agricultural campaigns. The findings underscore the pressing need to implement comprehensive long-term agricultural reforms that prioritize both environmental health and farmer livelihoods. Without a shift to environmentally friendly techniques, the dual burden of agricultural production and public health risk would continue to impede India's development aspirations.

***Keywords:* -** Pollution, Environmental impact, Health Risk, Mitigation Policies

INTRODUCTION

Agriculture is vital to India's economy, employing more than 40% of the workforce and making substantial contributions to food security and rural livelihoods [1]. However, the intensification of agricultural methods over the last few decades, particularly since the Green Revolution, has created a slew of environmental and public health issues [2]. With the introduction of high-yield crop types, a greater reliance on chemical fertilizers and pesticides, and mechanized farming techniques, Indian agriculture has evolved into a system that is both extremely productive and environmentally damaging [3].

One of the most noticeable consequences is increased environmental pollution, including contamination of air, water, and soil [4]. The annual burning of crop wastes in northern India, particularly in Punjab, Haryana, and western Uttar Pradesh, causes severe air pollution and contributes largely to the seasonal smog that blankets the Indo-Gangetic plain [5]. At the same time, the misuse of synthetic fertilizers and pesticides has contaminated groundwater, eutrophied water bodies, and harmed soil health. These contaminants threaten environmental stability and have severe consequences for human health (Parihar et al.,2023).

Numerous studies have connected agricultural pollution in India to a rise in respiratory illnesses, malignancies, endocrine problems, and waterborne diseases, particularly among rural and periurban populations [7]. Children, women, and farm laborers are particularly vulnerable to the effects of these contaminants. Despite increased awareness, policy interventions have been limited in scope or poorly enforced, while long-term options are underutilized due to economic, technical, and institutional hurdles [8]. This study aims to investigate the complex interactions among Indian agriculture, environmental pollution, and public health by utilizing environmental data analysis, health impact studies, and policy reviews [9]. Its goal is to quantify the environmental costs of agricultural activities, evaluate the direct and indirect effects on human health, and assess the efficacy of present mitigation efforts. The study's conclusions are designed to educate policymakers, academics, and stakeholders on the critical need for an integrated, sustainable strategy for agricultural development that balances productivity with environmental and public health concerns [10], [11].

METHODS

This study takes a mixed-methods approach to investigating the environmental and health consequences of farming practices in India. The methodology provides a thorough assessment by combining quantitative analysis of pollution data, satellite imaging, epidemiological investigations, and policy document reviews [12].

1. Study Design

The study is designed as a multidisciplinary, cross-sectional investigation with spatial and temporal dimensions. The study concentrates on high-intensity agricultural regions, such as

- Punjab, Haryana, and Uttar Pradesh (agricultural residue burning)(Lan et al. 2022a).
- Andhra Pradesh, Maharashtra, and Tamil Nadu (pesticide-intensive farming) [14]
- Ganga Basin states (for water pollution analysis. [15]

2. Data Sources

a. ***Environmental Pollution Data***

- Air quality indicators ($PM_{2.5}$, PM_{10}, CO, NOx, SO_2) were gathered [16] from:
  - Central Pollution Control Board (CPCB)
  - NASA's MODIS satellite data (fire counts and aerosol optical depth)
- Water quality data:[17]
  - Central Ground Water Board (CGWB)
  - National Water Quality Monitoring Programme (NWMP)
- Soil contamination:[18]
  - Indian Council of Agricultural Research (ICAR)
  - State agricultural universities and published soil health surveys

b. ***Public Health Data*** [19]

- Disease prevalence data (respiratory illnesses, malignancies, and developmental abnormalities) from [20]:
  - National Family Health Survey (NFHS-5)
  - National Sample Survey Office (NSSO)
  - Indian Council of Medical Research (ICMR)
  - WHO Global Health Observatory
- Hospital admission records and outpatient data from government hospitals, when applicable, are included.

c. ***Agricultural Practices***

- Data regarding crop patterns, fertilizer and pesticide usage, as well as residue management, can be obtained from [21].
  - Ministry of Agriculture and Farmers Welfare
  - Directorate of Economics and Statistics
  - Remote sensing data (e.g., Sentinel-2) is used to measure agricultural fire severity [22].

3. Analytical Methods

a. ***Geospatial Analysis*** [23]

- GIS mapping of crop burning hotspots, $PM_{2.5}$ concentrations, and health risk zones.
- Remote sensing was utilized to associate agricultural fires with long-term air quality degradation [24].

b. ***Statistical Analysis*** [25], [26]

- Descriptive statistics are used to summarize pollution levels and health impacts.
- Regression models are used to analyze the relationship between agricultural pollution and health indicators (such as the prevalence of respiratory sickness and waterborne infections).
- We conduct a time-series study to identify spikes in pollution and hospital visits during the crop burning season (October-November).

c. ***Health Risk Assessment*** [27]

- Disease burden (DALYs and deaths) estimates are based on WHO pollutant exposure threshold standards.
- Exposure-response functions were generated from global studies of air pollution and pesticide exposure [28].

d. *Policy Review*

- Qualitative evaluation of national and state policy, including [29]:
  - National Clean Air Programme (NCAP)
  - Soil Health Card Scheme
  - Bans and subsidies related to stubble burning and agrochemicals
- Stakeholder interviews (where accessible) are supplemented with government papers, NGO briefs, and academic critiques [30].

4. Limitations

- Limited access to district-level health outcome data may result in an underrepresentation of regional variability[31].
- Rural regions underreport pesticide exposure and respiratory illnesses due to limited healthcare access.
- Attributing health impacts to a single contaminant or source becomes challenging due to confounding environmental variables.

FINDINGS

The examination of environmental, agricultural, and public health data reveals that Indian farming methods have significant and measurable impacts on pollution levels and health outcomes. The findings are grouped by pollution type and associated health impacts [32].

1. Air Pollution caused by Crop Residue Burning [33]

- Residue burning is concentrated in Punjab and Haryana between October and November, which corresponds to the post-harvest time for paddy crops.
- MODIS satellite data showed a 300-400% increase in fire counts during this period, leading to regional $PM_{2.5}$ concentrations exceeding the WHO safe limit of 25 $\mu g/m^3$[34].
- A time-series study revealed a significant rise in hospital admissions for respiratory disorders during and immediately following the burning season, particularly in Delhi and the Indo-Gangetic Plain.
- Regression analysis found a significant positive connection ($r = 0.76$, $p < 0.01$) between fire activity and respiratory illness incidence[35].

- It is estimated that fine particle exposure from agricultural burning causes 44,000-98,000 premature deaths in India each year [36].

2. Water Pollution from Agrochemicals [37], [38]

- Nitrate concentrations in groundwater samples from agricultural areas exceeded 50 mg/L (the WHO permitted limit) in more than 30% of wells tested.
- Pesticide residues such as chlorpyrifos, endosulfan, and atrazine were found in surface and groundwater samples from states including Punjab, Maharashtra, and Andhra Pradesh.
- Regional health studies indicate that areas with high fertilizer consumption have a higher prevalence of gastrointestinal diseases and blue baby syndrome in neonates (methemoglobinemia).

3. Soil Degradation and Contamination [39], [40]

- Long-term fertilizer usage has caused soil acidification and micronutrient depletion, most notably zinc and iron shortages in the Indo-Gangetic and Deccan areas.
- Soil samples from pesticide-intensive farming zones included persistent organic pollutants (POPs), indicating threats to both environmental health and food safety.
- Reduced microbial activity and biodiversity in soil were also reported, jeopardizing long-term soil fertility [41].

4. Public Health Impacts [42]

- During high pollution seasons, the prevalence of chronic bronchitis, asthma, and COPD was greater among children and the elderly in rural agricultural districts.
- Hospital statistics showed a 20–25% increase in outpatient visits for respiratory illnesses in high-burning districts from October to January [43].
- Chronic pesticide exposure among farmers has been related to neurological diseases, hormonal abnormalities, and an increased risk of cancer, as substantiated by both self-reported symptoms and biochemical evaluations.
- Farmworkers who handled agrochemicals without protective gear had serum pesticide concentrations up to 2.5 times greater than WHO safety guidelines [44].

5. Effectiveness of Mitigation Policies [45]

- The use of Happy Seeder machines and in-situ residue management techniques lowered fire numbers by up to 40% in pilot districts that received governmental incentives and training.
- Organic agricultural projects under schemes such as the Paramparagat Krishi Vikas Yojana showed early success in reducing pesticide use, but they lacked scalability due to market and certification issues.
- Despite national regulations, enforcement of prohibited pesticide use is inadequate, particularly in smallholder and marginal farming groups [46].

6. Socioeconomic Disparities in Exposure and Impact [47]

- Poorer rural households experienced a disproportionate burden of exposure due to open-air cooking, inadequate ventilation, and restricted access to healthcare.
- Particularly in areas regularly experiencing severe water contamination and air pollution, women and children suffered disproportionately [48].
- Education and affluence showed a protective effect; better-informed farmers were more likely to employ protective equipment and conduct sustainable agriculture [49].

The study's findings underscore the complicated and increasingly unsustainable link between agricultural intensification in India and its environmental and public health consequences[50]. While agriculture remains a key component of the Indian economy, prevailing practices such as residue burning, excessive use of agrochemicals, and unsustainable irrigation have resulted in a twofold crisis: environmental degradation and increased health hazards for millions [51]

1. Agricultural Practices are a Major Source of Pollution

The study confirms that crop residue burning in North India is a significant seasonal source of severe air pollution, notably in the Indo-Gangetic Plain [52]. The timing of these fires corresponds with hazardous air quality levels in major cities such as Delhi, harming both urban and rural people[53]. While it is sometimes portrayed as a rural issue, our data reveal that the public health impacts are regional and long-term, exacerbated by meteorological circumstances such as low wind speeds and temperature inversions.

Similarly, the misuse of chemical fertilizers and pesticides degrades soil and water quality while also entering the human food chain. Water samples from important agricultural zones show contamination levels much beyond acceptable limits, increasing the risk of nitrate poisoning, hormonal abnormalities, and even carcinogenic exposure. These findings are especially troubling given India's heavy reliance on groundwater for irrigation and consumption [54].

2. Public Health Disparities and Vulnerable Populations [55]

The burden of pollution-related health effects falls disproportionately on vulnerable groups, including children, women, the elderly, and smallholder farmers. Limited awareness, limited access to healthcare [56], and a lack of preventative measures all contribute to increased exposure risks in rural locations. Children, for example, experience substantial decreases in lung function during crop-burning seasons, whilst farmers who are exposed to pesticides without protective equipment are at a higher risk of developing long-term neurological and hormonal issues.

These differences highlight the need to view pollution and its implications through a social determinant of health lens, recognizing that the same activities might have different effects depending on income, education, caste, gender, and region [57].

3. Limitations of Current Policy Interventions

Despite widespread awareness and repeated reform efforts, existing legislative solutions have been fragmented and under-enforced. Bans on stubble burning [58]For example, have proven ineffectual in the absence of cost-effective and accessible alternatives. Programs encouraging organic farming [59]Sustainable inputs are admirable, but they lack the institutional support, market access, and certification infrastructure required for broad adoption.

Furthermore, subsidies for chemical fertilizers continue to encourage excessive use, even as environmental deterioration intensifies. There is a gap between short-term economic incentives and long-term environmental sustainability [60], which frequently traps farmers in cycles of debt, soil weariness [61]and output stagnation.

4. The Need for Integrated Solutions

Addressing the simultaneous challenges of pollution and public health necessitates a systems-thinking strategy that connects the agriculture, environmental, and health sectors. To achieve sustainable agriculture in India, the following measures must be included [62].

- Incentivize low-emission technology (for example, Happy Seeder and direct planting).
- Strengthen rules on pesticides that are banned or dangerous.
- Promote integrated pest and nutrient management methods.
- Improve public health surveillance in agricultural areas.
- Improve farmer education on safe handling and disposal of agrochemicals.

Furthermore, climate-resilient agriculture policies must incorporate air quality targets and health effect evaluations into their planning and execution. The agricultural, environmental, health, and rural development ministries must work together across sectors [63].

RECOMMENDATIONS

To address the growing environmental and public health risks posed by Indian agricultural practices, a multifaceted, systems-based strategy is required. The proposals listed below are organized into policy, technology, health, education, and capacity-building programs targeted at promoting sustainable agriculture and minimizing its negative externalities [64].

1. Policy-Level Interventions [65]

- Eliminate blanket subsidies for chemical fertilizers and replace them with targeted incentives for organic and bio-based inputs.
- Strengthen and enforce hazardous pesticide restrictions, and encourage the speedy approval of eco-friendly alternatives (for example, neem-based or microbial biopesticides).
- Expand programs like the National Mission for Sustainable Agriculture (NMSA) to include required health effect studies of important agricultural practices in policymaking.
- Integrate agricultural emissions (particularly from residue burning and livestock) into India's national and state climate action plans (NAPCC and SAPCCs), along with enforceable air quality targets [66].

2. Technological and On-Ground Solutions [67]

- Increase the distribution and subsidization of in-situ equipment for managing crop residue (e.g., Happy Seeder, Super Straw Management System) to prevent burning [68].
- Promote zero-tillage and precision farming techniques to reduce soil disturbance, greenhouse gas emissions, and input efficiency.
- Encourage crop diversity and rotational cropping to lessen reliance on water- and fertilizer-intensive crops such as rice and sugarcane.
- Increase the use of remote sensing and GIS-based tools to monitor agricultural pollution and forecast seasonal pollution episodes.

3. Public Health & Safety Measures [69]

- Set up health surveillance systems in high-risk farming districts to monitor disease epidemics caused by pollution (e.g., respiratory, gastrointestinal, neurological).
- Mandatory health checks and medical insurance coverage for agricultural workers, particularly those who use agrochemicals.
- Enforce the use of personal protection equipment (PPE) during pesticide application, and promote the availability and affordability of such equipment in rural markets.
- Encourage community-based water quality testing and purification programs in regions with high nitrate and pesticide contamination.

4. Education, Awareness & Farmer Capacity Building [70]

- Launch widespread awareness campaigns about the environmental and health repercussions of residue burning, pesticide usage, and groundwater extraction [71].
- Integrate sustainable agriculture and environmental health into farmer training programs offered by Krishi Vigyan Kendras (KVKs) and agricultural universities [72].
- Create farmer-led demonstration models for sustainable farming methods to foster local champions and peer-to-peer learning.
- Engage women and youth in community-based monitoring and knowledge sharing to increase local ownership of sustainable practices.

5. Institutional and Research Support [73]

- Increase governmental and corporate funding for research and development of low-input, high-efficiency agricultural methods customized to Indian agroclimatic zones [74].
- Increase collaboration among the agriculture, environment, and health ministries to develop uniform policy frameworks.
- Create a national agricultural pollution database to detect changes in soil, air, and water quality and inform prompt actions.
- Support independent methods for assessing the environmental and health impacts of agriculture policies and projects.

CONCLUSION

Indian agriculture is important for the country's economic growth and food security, but it is also becoming more and more linked to serious damage to the environment and health risks for the public. The study found that common practices like burning crop waste, using too many chemical fertilizers and pesticides, and using irrigation systems that aren't sustainable all make the air, water, and soil much more polluted. These effects on the environment, in turn, have direct and visible effects on human health, including heart and lung disease, neurological and developmental problems, and more.

The study also found that agricultural pollution has a bigger impact on rural areas, smallholder farmers, women, and children because they are more exposed and vulnerable. Existing policy efforts haven't worked very well because they aren't enforced well, there aren't enough scalable alternatives, and not enough farmers are involved. If India doesn't make urgent, coordinated, and systematic changes, the pollution and health crises will get worse, putting the country's progress toward sustainable development goals at risk.

To solve these problems that are all related, the agriculture sector needs to use practices that are better for the environment, can withstand climate change, and are advantageous for health. This requires policy changes, new technologies, and more cooperation and participation from institutions. India's agriculture and people need a long-term plan that balances production, protects the environment, and ensures public health.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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