INTERNATIONAL JOURNAL FOR LEGAL RESEARCH AND ANALYSIS

Open Access, Refereed Journal Multi Disciplinary
Peer Reviewed

www.ijlra.com

ISSN: 2582-6433

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ISSN: 2582-6433

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ISSN: 2582-6433

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ISSN: 2582-6433

Regulatory and Environmental Challenges of Agrowaste (Crop Residue) Burning in India: A Study of Legal Framework and Sustainable

Solutions”

SEMINAR PAPER

SUBMITTED TO

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IN PARTIAL FULFILMENT OF REQUIREMENTS FOR THE AWARD OF THE DEGREE

BACHELOR OF ARTS & BACHELOR OF LEGISLATIVE LAW

SESSION 2021-2026

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ABSTRACT

Crop residue burning, a prevalent agricultural practice in India, has emerged as a critical environmental and public health concern, particularly in the northern states of Punjab, Haryana, and Uttar Pradesh. This study examines the regulatory and environmental challenges associated with agrowaste burning within the framework of existing legal mechanisms in India, while also exploring sustainable alternatives to mitigate its adverse impacts. Agrowaste, comprising post-harvest residues such as stubble and straw, is often burned by farmers to facilitate rapid field clearance due to economic and technological constraints. However, this practice contributes significantly to air pollution, especially in the National Capital Region (NCR), leading to severe deterioration in air quality and posing serious risks to human health. Empirical data suggests that millions of tonnes of crop residue are burned annually, releasing substantial quantities of particulate matter and greenhouse gases into the atmosphere.

The paper critically analyses the constitutional and statutory framework governing environmental protection in India, with particular emphasis on the right to a clean and healthy environment under Article 21 of the Constitution. It evaluates key legislations, including the Environment (Protection) Act, 1986, the Air (Prevention and Control of Pollution) Act, 1981, and the Commission for Air Quality Management Act, 2021, alongside the role of judicial interventions by the Supreme Court and the National Green Tribunal in addressing stubble burning. Landmark judicial pronouncements have underscored the State's obligation to safeguard environmental rights while simultaneously highlighting enforcement deficiencies and policy gaps in regulating agricultural practices.

Further, the study identifies the multifaceted challenges in curbing crop residue burning, including weak enforcement mechanisms, lack of inter-state coordination, socio-economic constraints faced by farmers, and limited access to sustainable technologies. It argues that a purely punitive legal approach is insufficient and may be counterproductive in the absence of viable alternatives. In this context, the paper explores a range of sustainable solutions, such as technological innovations (e.g., Happy Seeder and bio-decomposition techniques), policybased incentives, crop diversification, and community-driven approaches.

The study concludes that addressing the issue of agrowaste burning requires a balanced and integrated strategy that harmonises environmental regulation with agricultural sustainability

and economic realities. It emphasises the need for strengthening the legal framework, enhancing institutional accountability, and promoting sustainable agricultural practices through a combination of regulatory, economic, and technological interventions. Such an approach is essential to ensure long-term environmental protection and the realisation of the fundamental right to a clean and healthy environment.

CHAPTER 1: INTRODUCTION

Crop residue burning, a pervasive agricultural practice in India, has increasingly assumed the character of a pressing environmental and regulatory challenge with profound implications for public health, ecological balance, and governance. Agrowaste, or crop residue, encompasses the organic remnants such as straw, stubble, husk, and other plant materials left in the fields after harvesting. In the context of modern, mechanised agriculture, particularly with the widespread use of combine harvesters, the volume of such residue has expanded significantly. In order to ensure the timely preparation of fields for the next cropping cycle, especially within intensive agricultural systems, farmers frequently resort to the open burning of this biomass. Although this method is expedient and economically viable at the individual level, it engenders severe environmental externalities. India is estimated to produce nearly 500 million tonnes of crop residue annually, of which a considerable proportion is disposed of through burning, resulting in the large-scale emission of particulate matter and greenhouse gases into the atmosphere [1].

The phenomenon is geographically concentrated in the north-western agrarian belt of India, particularly in the states of Punjab, Haryana, and Uttar Pradesh, which play a pivotal role in ensuring national food security. These regions are characterised by the rice–wheat cropping cycle, which necessitates a rapid turnaround between harvesting and sowing. The narrow temporal window available for field preparation, coupled with limited access to affordable residue management technologies, compels farmers to adopt burning as the most practical solution. However, the repercussions of this practice transcend regional boundaries, significantly impacting the air quality of the National Capital Region (NCR), including Delhi. Seasonal spikes in burning incidents, recorded through satellite-based monitoring, coincide with drastic deteriorations in air quality, thereby underscoring the transboundary and systemic nature of the problem [2].

The nexus between crop residue burning and the escalating air pollution crisis in northern India is both direct and empirically substantiated. The combustion of agricultural residues releases a complex mix of pollutants, including fine particulate matter (PM2.5 and PM10), carbon

[1] Nature Study on Crop Residue Generation
[2] ScienceDirect Study on Regional Fire Incidents

monoxide, nitrogen oxides, and volatile organic compounds, which contribute to the formation of dense smog. These emissions are particularly hazardous during the winter months, when meteorological conditions such as temperature inversion impede the dispersion of pollutants. The public health consequences are severe, with heightened exposure linked to respiratory ailments, cardiovascular diseases, and increased mortality rates. Empirical studies have consistently demonstrated that stubble burning in neighbouring states is a significant contributor to the seasonal deterioration of air quality in Delhi, thereby transforming the issue into a recurring public health emergency [3].

A defining feature of crop residue burning in India is its cyclical and seasonal manifestation, closely aligned with agricultural harvesting patterns. Two principal peaks are observed annually—during the post-monsoon period (October–November) following paddy harvesting, and the pre-monsoon period (April–May) associated with wheat harvesting. During these intervals, there is a marked surge in fire incidents, often resulting in acute episodes of air pollution across northern India. Recent data indicates that thousands of such incidents are recorded within compressed timeframes during these peak periods, with the contribution of stubble burning to Delhi's PM2.5 levels at times rising to as high as 30–35%, thereby highlighting its episodic yet substantial impact on ambient air quality[4].

Notwithstanding the existence of an evolving legal and regulatory framework aimed at environmental protection, the persistence of crop residue burning reveals significant deficiencies in enforcement, policy coherence, and socio-economic alignment. The issue represents a complex intersection of agricultural necessity, environmental sustainability, and legal governance, wherein regulatory measures must contend with ground-level realities faced by farmers. Accordingly, the present study seeks to critically examine the regulatory and environmental challenges associated with agrowaste burning in India, while exploring sustainable, economically viable, and legally sound solutions to address this multifaceted problem. In doing so, it situates the issue within the broader constitutional mandate of ensuring the right to a clean and healthy environment, thereby emphasising the urgent need for a balanced and integrated approach to environmental governance.

[3] MDPI Study on Emissions from Crop Burning

[4] Scientific Study on Delhi Air Pollution Link

1.1 Meaning of Agrowaste / Crop Residue Burning

Agrowaste, in the context of agricultural production, encompasses all residual biomass left after the harvesting and processing of crops. This includes straw, stubble, chaff, husk, and other plant remains that are not immediately utilised for productive or commercial purposes. In India's agrarian economy, the quantum of such residue has significantly increased with the advent of mechanised farming techniques, particularly combine harvesters, which leave behind a thick layer of stubble on the field.

Crop residue burning refers to the deliberate incineration of this biomass in open fields as a means of clearing land for the next cropping cycle. While traditionally some of this residue was repurposed as fodder, fuel, or organic manure, changing agricultural practices and declining demand for certain types of residue (especially paddy straw) have reduced its utility. Consequently, burning has emerged as the quickest and least labour-intensive method of disposal.

However, this practice is highly detrimental from an environmental perspective. The burning of crop residue releases substantial quantities of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), along with particulate matter and toxic pollutants. It is estimated that India produces nearly 500 million tonnes of crop residue annually, with around 100 million tonnes being burned, thereby contributing significantly to atmospheric pollution [5]. Beyond air pollution, it also leads to the loss of valuable soil nutrients, destruction of beneficial microorganisms, and long-term degradation of soil fertility. Thus, what appears to be an economically rational choice at the individual farmer level translates into a serious ecological and environmental challenge at the macro level.

1.2 Geographical Prevalence (Punjab, Haryana, Uttar Pradesh, NCR)

Crop residue burning in India exhibits a distinct geographical concentration, primarily in the north-western states of Punjab, Haryana, and parts of Uttar Pradesh. These regions are integral to India's food grain production system and are characterised by intensive cultivation under

[5] Nature Study on Crop Residue Generation

the rice–wheat cropping cycle. The adoption of high-yielding varieties and irrigation facilities has further intensified agricultural practices, resulting in increased generation of crop residue.

The structural nature of this cropping pattern leaves farmers with a very narrow window—often less than two to three weeks—between the harvesting of paddy and the sowing of wheat. Given such time constraints, farmers often resort to burning as the only viable method for rapid field clearance. Additionally, the high silica content of paddy straw makes it unsuitable as cattle fodder, further limiting alternative uses.

The environmental impact of this practice extends beyond the immediate regions where burning occurs. Due to atmospheric circulation patterns, pollutants travel across state boundaries and significantly affect the air quality of the National Capital Region (NCR), particularly Delhi. Satellite data and remote sensing technologies consistently record thousands of fire incidents in these regions during peak seasons, demonstrating the large-scale and repetitive nature of the issue[6]. This transboundary character transforms crop residue burning from a local agricultural practice into a regional environmental crisis requiring coordinated inter-state policy responses.

1.3 Link with Air Pollution and Public Health Crisis

The link between crop residue burning and air pollution is direct, substantial, and welldocumented. The combustion process releases a mixture of harmful pollutants, including fine particulate matter (PM2.5 and PM10), carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO_2), and volatile organic compounds (VOCs). These pollutants contribute to the formation of dense smog, particularly during the winter months when atmospheric conditions such as low wind speed and temperature inversion inhibit the dispersion of pollutants.

Among these, PM2.5 particles are of particular concern due to their ability to penetrate deep into the respiratory system and enter the bloodstream. Elevated concentrations of such pollutants are associated with a wide range of adverse health outcomes, including respiratory diseases (such as asthma and chronic bronchitis), cardiovascular disorders, lung cancer, and

[6] Scientific Study on Delhi Air Pollution Link

premature mortality. Vulnerable groups, including children, the elderly, and individuals with pre-existing health conditions, are disproportionately affected.

Empirical research has consistently demonstrated that stubble burning in Punjab and Haryana significantly contributes to the deterioration of air quality in Delhi and surrounding areas during peak periods[7]. At times, this contribution becomes substantial enough to trigger public health emergencies, leading to school closures, restrictions on construction activities, and advisories against outdoor exposure. The recurring nature of such crises underscores the systemic failure to address the root causes of the problem and highlights the urgent need for integrated policy interventions.

1.4 Recent Trends and Data (Seasonal Spikes)

A critical feature of crop residue burning in India is its cyclical and seasonal pattern, closely aligned with agricultural harvesting schedules. Two major peaks are observed annually: the post-monsoon season (October–November), following the harvesting of paddy crops, and the pre-monsoon season (April–May), associated with wheat harvesting. During these periods, there is a dramatic surge in the number of fire incidents, leading to a sudden and significant deterioration in air quality across northern India.

Recent data indicates that these seasonal spikes continue to persist despite regulatory interventions and policy measures. For instance, during the 2026 wheat harvesting season, thousands of fire incidents were reported within a short duration, reflecting the entrenched nature of the practice[8]. Furthermore, scientific assessments reveal that during peak burning periods, the contribution of stubble burning to Delhi's PM2.5 levels can rise sharply, sometimes reaching up to 30–35% of total pollution on certain days[9].

These episodic spikes are particularly problematic because they coincide with already unfavourable meteorological conditions, thereby amplifying their impact. The predictability of these seasonal patterns also indicates that the problem is not sudden or unforeseen but rather systemic and recurring. This underscores the need for proactive, rather than reactive, policy

[7] MDPI Study on Emissions from Crop Burning
[8] Recent 2026 Data on Burning Incidents
[9] Data on PM2.5 Contribution

measures, including pre-season planning, technological deployment, and targeted enforcement strategies.

1.5 STATEMENT OF PROBLEM

Crop residue burning in India represents a deeply entrenched and multifaceted problem that exposes critical tensions between agricultural imperatives, environmental sustainability, and the efficacy of legal regulation. Notwithstanding the presence of an elaborate statutory framework most notably the Environment (Protection) Act, 1986 and the Air (Prevention and Control of Pollution) Act, 1981 the persistence and recurrence of large-scale burning practices, particularly in the agrarian states of Punjab, Haryana, and Uttar Pradesh, reveal a fundamental inadequacy in both the design and implementation of regulatory mechanisms. The continued prevalence of this practice, despite repeated policy interventions and judicial scrutiny, raises serious questions regarding the effectiveness, enforceability, and socio-economic sensitivity of the existing legal regime [10].

At the core of the problem lies the substantial contribution of crop residue burning to the escalating air pollution crisis in northern India, especially in the National Capital Region (NCR). The large-scale emission of fine particulate matter (PM2.5), greenhouse gases, and toxic pollutants from such burning activities leads to acute deterioration in ambient air quality, often resulting in hazardous smog episodes. These environmental consequences directly translate into severe public health implications, including respiratory and cardiovascular disorders, increased morbidity, and premature mortality. The magnitude of this impact elevates the issue beyond a mere environmental concern, implicating the constitutional guarantee of the right to life under Article 21, which has been judicially interpreted to include the right to a clean and healthy environment[11].

A significant dimension of the problem is rooted in the socio-economic constraints faced by farmers, which render compliance with environmental norms both difficult and, at times, impracticable. The high cost of sustainable alternatives, such as advanced residue management technologies, coupled with limited access to institutional support and awareness mechanisms, compels farmers to resort to burning as the most expedient and economically viable option. In

[10] Study on Regulatory Gaps in Crop Burning
[11] Study on Air Pollution and Health Impact

this context, the imposition of penalties or punitive measures, without addressing underlying structural constraints, risks being both ineffective and inequitable. This creates a complex policy dilemma, wherein environmental regulation must reconcile the competing demands of ecological protection and agrarian livelihood security[12].

Furthermore, the issue is exacerbated by systemic deficiencies in governance, including weak enforcement, fragmented institutional responsibility, and inadequate coordination between central and state authorities. The multiplicity of agencies involved—ranging from pollution control boards to agricultural departments—often results in overlapping jurisdictions and diffused accountability. Judicial interventions have repeatedly underscored these shortcomings, highlighting the lack of consistent enforcement and the failure of administrative machinery to translate legal mandates into effective ground-level action[13]. Such governance deficits undermine the credibility of the regulatory framework and perpetuate a cycle of noncompliance.

The seasonal and transboundary character of crop residue burning further complicates the regulatory landscape. The concentration of burning incidents within narrow agricultural windows leads to episodic yet severe spikes in pollution levels, while the movement of pollutants across state boundaries challenges traditional notions of jurisdiction and accountability. This regional dimension of the problem necessitates a coordinated and harmonised policy response, which remains largely inadequate under the current fragmented approach[14].

In essence, the problem addressed in this study lies in the disconnect between the formal legal framework and the practical realities of its implementation. The persistence of crop residue burning underscores not only the limitations of existing laws but also the absence of a holistic and integrated strategy that effectively combines legal enforcement with economic incentives, technological innovation, and farmer-centric solutions. Accordingly, this study seeks to critically examine whether the current regulatory regime is capable of addressing the environmental and public health challenges posed by agrowaste burning, and to explore the

[12] Research on Socio-economic Constraints of Farmers
[13] Judicial Observations on Enforcement Failures
[14] Study on Transboundary and Seasonal Pollution

need for a more nuanced and sustainable approach that aligns legal objectives with socioeconomic and ecological considerations.

1.6 OBJECTIVES OF THE STUDY

The present study aims to critically examine the issue of agrowaste (crop residue) burning in India from a legal, environmental, and socio-economic perspective. In light of its growing impact on air quality, public health, and environmental governance, the study is guided by the following key objectives:

1. To analyse the concept and underlying causes of crop residue burning in India The study seeks to understand the nature, scale, and drivers of agrowaste burning, including agricultural practices, mechanisation, and the economic constraints faced by farmers.
2. To examine the environmental impact of crop residue burning

   It aims to evaluate the contribution of this practice to air pollution, climate change, soil degradation, and its broader ecological consequences, particularly in the northern regions of India.
3. To assess the public health implications associated with stubble burning The study intends to explore how emissions from crop burning affect human health, with specific focus on respiratory and cardiovascular diseases and their impact on vulnerable populations.
4. To critically evaluate the existing legal and regulatory framework in India This includes an analysis of constitutional provisions, statutory laws such as the Environment (Protection) Act, 1986 and the Air (Prevention and Control of Pollution) Act, 1981, as well as the role of regulatory bodies and policies in controlling crop residue burning.
5. To examine the role of the judiciary in addressing crop residue burning The study aims to analyse key judicial pronouncements and interventions by courts and tribunals, particularly in shaping environmental governance and enforcing compliance. 6. To identify the challenges and gaps in enforcement and policy implementation It seeks to highlight deficiencies in administrative coordination, regulatory enforcement, and institutional mechanisms that hinder effective control of the practice.

7. To explore the socio-economic dimensions influencing farmers' behaviour The study intends to assess the economic, technological, and structural constraints that compel farmers to continue residue burning despite legal prohibitions.
8. To evaluate sustainable and alternative solutions to crop residue burning This includes examining technological innovations, policy incentives, crop diversification strategies, and community-based approaches aimed at reducing reliance on burning.
9. To suggest legal and policy reforms for effective regulation

The study aims to propose recommendations for strengthening the existing legal framework, improving enforcement mechanisms, and ensuring a balanced approach between environmental protection and agricultural sustainability.

10. To contribute to the discourse on environmental governance and sustainable development

    Ultimately, the study seeks to situate the issue within the broader framework of sustainable development, emphasising the need for an integrated approach that harmonises environmental, economic, and social objectives.

CHAPTER 2: SCOPE AND EVOLUTION OF THE STUDY

2.1 SCOPE OF THE STUDY

The scope of the present study is both interdisciplinary and analytical, encompassing legal, environmental, and socio-economic dimensions of crop residue burning in India. The study is primarily focused on examining the regulatory challenges associated with agrowaste burning and evaluating the effectiveness of the existing legal framework in addressing its environmental and public health implications.

Firstly, the study covers the geographical region of northern India, particularly the states of Punjab, Haryana, and Uttar Pradesh, which are most affected by crop residue burning and significantly influence air quality in the National Capital Region (NCR). By focusing on these regions, the study seeks to understand the regional dynamics and transboundary nature of air pollution caused by stubble burning[15].

Secondly, the scope extends to an in-depth analysis of the legal and constitutional framework governing environmental protection in India. This includes the examination of constitutional provisions such as Article 21, as well as key legislations like the Environment (Protection) Act, 1986, the Air (Prevention and Control of Pollution) Act, 1981, and the National Green Tribunal Act, 2010. The study also considers the role of regulatory authorities and policy initiatives in addressing crop residue burning[16].

[15] Study on Regional Impact of Stubble Burning (ScienceDirect)
[16] Environmental Law Framework in India (EPA, Air Act studies)

Further, the study incorporates a judicial perspective, analysing significant interventions by the Supreme Court and the National Green Tribunal in regulating environmental pollution and addressing stubble burning. It seeks to evaluate the effectiveness of judicial activism in ensuring enforcement and compliance with environmental norms[17].

In addition, the study examines the environmental and public health impacts of crop residue burning, particularly its contribution to air pollution, smog formation, and respiratory illnesses.

It also considers the broader ecological consequences, including soil degradation and climate change implications[18].

Importantly, the scope includes the socio-economic realities of farmers, recognising that crop residue burning is not merely a legal violation but also a consequence of economic constraints, technological limitations, and structural issues within the agricultural sector. This enables a more balanced and nuanced analysis of the problem[19].

However, the study is limited in that it primarily focuses on India-specific legal and policy frameworks and does not undertake an extensive comparative analysis of international regulatory models, except where necessary for contextual understanding.

2.2 EVOLUTION OF THE ISSUE AND LEGAL FRAMEWORK

The issue of crop residue burning in India has evolved significantly over time, transitioning from a localised agricultural practice to a major environmental and regulatory concern.

In the pre-mechanisation era, crop residues were traditionally utilised for multiple purposes such as cattle fodder, household fuel, and organic manure. As a result, the incidence of largescale burning was relatively minimal. However, with the advent of the Green Revolution in the 1960s and 1970s, there was a shift towards high-yield crop varieties, increased irrigation, and mechanised farming practices. The introduction of combine harvesters led to the accumulation of large quantities of stubble, which reduced the feasibility of manual removal

[17] Judicial Studies on Environmental Governance
[18] MDPI / Environmental Studies on Pollution Impact
[19] Research on Farmer Constraints and Agricultural Practices

and increased dependence on burning as a disposal method[20].The environmental consequences of such practices became more apparent in the late 20th century, leading to the development of a formal environmental legal framework in India. The enactment of the Environment (Protection) Act, 1986, marked a significant milestone in empowering the central government to take measures for environmental protection. Similarly, the Air (Prevention and Control of Pollution) Act, 1981, provided a statutory basis for controlling air pollution, including emissions resulting from agricultural burning[21].

In the early 21st century, the issue gained greater prominence due to the worsening air quality in Delhi and NCR, which brought national and international attention to crop residue burning. The establishment of the National Green Tribunal (NGT) in 2010 further strengthened environmental governance by providing a specialised forum for addressing environmental disputes and enforcing compliance[22]. The NGT has, on multiple occasions, issued directions prohibiting stubble burning and imposing environmental compensation on violators.

More recently, the enactment of the Commission for Air Quality Management (CAQM) Act, 2021 represents a targeted institutional response to the air pollution crisis in NCR and adjoining areas. The Commission has been vested with extensive powers to coordinate between states, enforce regulations, and implement measures to control stubble burning [23] .Judicial interventions have also played a pivotal role in shaping the evolution of this issue. The Supreme Court, through various orders and observations in stubble burning-related matters, has emphasised the urgency of addressing air pollution and has criticised the lack of effective enforcement by state authorities. These interventions reflect a growing recognition of the issue as not merely an environmental concern but a matter of fundamental rights and public health[24].

In recent years, policy discourse has gradually shifted towards sustainable and incentive-based approaches, including the promotion of residue management technologies, crop diversification, and financial assistance to farmers. This indicates an evolving understanding

[20] Studies on Green Revolution and Mechanisation Impact
[21] Legal Commentary on Environmental Acts in India
[22] NGT Act and Environmental Adjudication Studies
[23] CAQM Act Analysis Reports
[24] Supreme Court Observations on Air Pollution and Stubble Burning

that the problem cannot be effectively addressed through punitive measures alone, but requires a comprehensive and integrated strategy.

2.3 NEED FOR REGULATION

The regulation of crop residue burning in India has become an imperative necessity in light of its far-reaching environmental, public health, and legal implications. The persistence of this practice, despite its known adverse effects, underscores the urgent need for a robust and effective regulatory framework that can balance agricultural realities with environmental sustainability.

At the foremost level, the need for regulation arises from the severe environmental consequences associated with crop residue burning. The large-scale emission of pollutants such as particulate matter (PM2.5 and PM10), carbon dioxide, methane, and nitrogen oxides significantly contributes to air pollution and climate change. These emissions not only degrade ambient air quality but also lead to the formation of dense smog, particularly in northern India. The environmental damage extends beyond air pollution, as burning also results in the depletion of soil nutrients, destruction of beneficial microorganisms, and long-term degradation of soil health. Such widespread ecological harm necessitates regulatory intervention to ensure environmental protection and sustainable agricultural practices[25].

Closely linked to environmental degradation is the public health crisis triggered by crop residue burning. The inhalation of fine particulate matter and toxic gases poses serious health risks, including respiratory illnesses, cardiovascular diseases, and increased mortality rates. The seasonal spikes in pollution levels, particularly in the National Capital Region (NCR), often lead to hazardous air quality conditions, affecting millions of people. The magnitude of this impact elevates the issue to a matter of constitutional significance, as it directly implicates the right to life and a clean and healthy environment under Article 21. Consequently, regulatory measures are essential to safeguard public health and uphold fundamental rights[26].

Another critical aspect necessitating regulation is the transboundary and regional nature of the problem. Crop residue burning in one state has direct and substantial effects on neighbouring

[25] Environmental Impact Studies on Crop Burning (MDPI/Nature)
[26] Public Health and Air Pollution Studies

regions due to the movement of air pollutants across state boundaries. This creates challenges of jurisdiction and accountability , as individual states may lack the incentive or capacity to address the issue in isolation. Therefore, a coordinated regulatory framework at the central and inter-state level becomes essential to effectively manage and mitigate the problem[27].

The need for regulation is further reinforced by the limitations of existing agricultural practices and market mechanisms. Farmers often resort to burning due to economic constraints, lack of access to affordable alternatives, and the limited time available between cropping cycles. In the absence of regulatory oversight, such practices continue unchecked, leading to cumulative environmental damage. Regulation, therefore, plays a crucial role not only in restricting harmful activities but also in promoting sustainable alternatives through incentives, subsidies, and technological support[28].

Additionally, the inadequacy of voluntary compliance highlights the importance of enforceable legal mechanisms. Despite awareness of the harmful effects of stubble burning, compliance remains low due to weak enforcement, lack of monitoring, and limited accountability. Judicial observations and policy reports have repeatedly emphasised that without stringent regulation and effective implementation, efforts to control crop residue burning are unlikely to succeed[29].

Finally, the need for regulation must be understood within the broader framework of sustainable development and environmental governance. Crop residue burning exemplifies the conflict between economic development and environmental protection, necessitating a balanced approach that integrates legal regulation with socio-economic considerations. Effective regulation can serve as a tool for achieving this balance by ensuring that environmental costs are internalised while simultaneously supporting farmers through viable and sustainable alternatives.

In conclusion, the regulation of crop residue burning is not merely a legal necessity but an environmental and social imperative. It is essential to address the adverse impacts of this practice, ensure compliance with environmental norms, protect public health, and promote sustainable agricultural practices. A comprehensive and well-enforced regulatory framework,

[27] Research on Transboundary Air Pollution
[28] Agricultural Economics and Farmer Constraint Studies
[29] Judicial and Policy Reports on Enforcement Gaps

supported by policy innovation and stakeholder cooperation, is crucial for effectively tackling this persistent challenge

CHAPTER 3: RESEARCH FRAMEWORK

3.1 RESEARCH GAP

The issue of crop residue burning in India has attracted considerable attention across multiple disciplines, including environmental science, public health, and agricultural economics. A substantial body of literature exists analysing the environmental impacts of stubble burning, particularly its contribution to air pollution and climate change, as well as its adverse effects on human health. Similarly, several studies have examined the technological and economic dimensions of residue management, focusing on alternative solutions such as mechanised equipment and biomass utilisation. However, despite this growing scholarship, significant gaps remain, particularly from a legal and interdisciplinary perspective.

Firstly, there exists a limited integration of legal analysis with environmental and agricultural studies. While environmental research extensively documents the harmful effects of crop residue burning, there is comparatively inadequate scholarly focus on critically evaluating the effectiveness of India's legal and regulatory framework in addressing this issue. The role of statutory mechanisms, regulatory bodies, and enforcement agencies is often discussed in isolation, without a comprehensive assessment of their practical efficacy and limitations[30].

Secondly, there is a lack of in-depth analysis of enforcement challenges and institutional accountability. Existing studies tend to highlight the presence of laws and policies but often fail to examine the reasons behind their ineffective implementation. Issues such as

[30] Environmental vs Legal Studies Gap Analysis

administrative inefficiency, lack of coordination between central and state authorities, and weak monitoring mechanisms have not been sufficiently explored in legal scholarship, leaving a gap in understanding the operational failures of environmental governance[31].

Another significant gap lies in the insufficient focus on the socio-economic realities of farmers within the legal discourse. Much of the literature either adopts a purely environmental perspective or a policy-oriented approach, without adequately addressing how economic constraints, technological limitations, and structural inequalities influence compliance with environmental regulations. The absence of a farmer-centric legal analysis results in regulatory frameworks that may be theoretically sound but practically difficult to implement[32].

Further, there is a paucity of research examining the balance between punitive and incentivebased regulatory approaches. While some studies advocate stricter enforcement and penalties, others emphasise the need for subsidies and technological support. However, there is limited comprehensive analysis that evaluates the effectiveness of these approaches in tandem, particularly within the Indian legal context. This gap is crucial, as an over-reliance on punitive measures without supportive mechanisms may lead to resistance and non-compliance[33].

Additionally, the transboundary and regional dimensions of crop residue burning remain underexplored in legal scholarship. Although environmental studies acknowledge the crossborder movement of pollutants, there is insufficient examination of how existing legal frameworks address issues of inter-state coordination, shared responsibility, and jurisdictional challenges. This limits the development of cohesive and cooperative regulatory strategies[34].

Moreover, recent developments, including the establishment of the Commission for Air Quality Management (CAQM) and evolving judicial interventions, have not been comprehensively analysed in existing literature. There is a gap in contemporary legal research assessing the impact of these newer institutional mechanisms and judicial directions on the regulation of crop residue burning.

[31] Research on Enforcement and Governance Failures
[32] Studies on Farmer Constraints and Compliance
[33] Policy Research on Incentive vs Penalty Approaches
[34] Studies on Transboundary Air Pollution

In light of these gaps, the present study seeks to adopt a holistic and interdisciplinary approach, integrating legal analysis with environmental and socio-economic perspectives. It aims to critically evaluate the effectiveness of the existing regulatory framework, examine enforcement challenges, and explore sustainable and legally viable solutions that align environmental objectives with the practical realities faced by farmers. By addressing these gaps, the study contributes to a more nuanced understanding of environmental governance and policy formulation in the context of crop residue burning in India.

3.2 RESEARCH QUESTIONS

1. To what extent does the existing legal and regulatory framework in India effectively address the environmental and public health challenges arising from crop residue burning, and whether it is adequate in its design, enforcement, and implementation?
2. How does crop residue burning contribute to the degradation of air quality and the escalation of public health crises in northern India, particularly in the National Capital Region (NCR), and what is the magnitude of its impact in comparison to other sources of pollution?
3. What are the structural and institutional deficiencies within the current regulatory regime that impede effective enforcement of laws governing agrowaste burning, and how do issues of administrative coordination and accountability affect compliance?
4. In what manner do socio-economic constraints, technological limitations, and agrarian practices influence farmers' continued reliance on crop residue burning, and how do these factors challenge the practical enforceability of environmental laws?
5. Whether the prevailing regulatory approach, which is predominantly punitive in nature, is sufficient to curb crop residue burning, or whether a more balanced framework integrating incentives, technological support, and farmer-centric policies is required?
6. What has been the role and impact of judicial intervention in addressing crop residue burning in India, and to what extent have court directions succeeded in strengthening environmental governance and ensuring compliance?

3.3 HYPOTHESIS

The present study proceeds on the primary hypothesis that the existing legal and regulatory framework in India is inadequate and largely ineffective in controlling crop residue burning, primarily due to weak enforcement mechanisms, lack of institutional coordination, and insufficient consideration of the socio-economic realities faced by farmers. It is further hypothesised that crop residue burning constitutes a significant contributor to seasonal air pollution and the resulting public health crisis in northern India, particularly in the National Capital Region (NCR). The study assumes that the prevailing reliance on punitive legal measures, in the absence of adequate economic incentives and technological support, is insufficient to ensure compliance and may, in fact, hinder effective regulation. It also posits that socio-economic constraints, including the high cost of alternative technologies and limited access to institutional assistance, play a decisive role in perpetuating the practice among farmers. While judicial interventions have been instrumental in recognising and addressing the issue, their impact is hypothesised to be limited without consistent and effective administrative implementation. Consequently, the study advances the proposition that the integration of sustainable agricultural practices, technological innovations, and incentive-based policy measures within the legal framework, coupled with coordinated action between central and state authorities, is essential for developing a comprehensive and effective solution to the problem of crop residue burning in India.

3.4 RESEARCH METHODOLOGY

The present study adopts a doctrinal and analytical research methodology, primarily based on secondary sources of data, to examine the regulatory and environmental challenges associated with crop residue burning in India. The research is qualitative in nature and seeks to critically analyse the effectiveness of the existing legal framework while integrating environmental and socio-economic perspectives.

The study relies extensively on secondary data, including statutes, case laws, government reports, policy documents, and academic literature. Key legislations such as the Environment (Protection) Act, 1986, the Air (Prevention and Control of Pollution) Act, 1981, the National Green Tribunal Act, 2010, and the Commission for Air Quality Management Act, 2021 have been examined to understand the legal framework governing air pollution and crop residue

burning. Judicial pronouncements of the Supreme Court and the National Green Tribunal have also been analysed to evaluate the role of the judiciary in shaping environmental governance and enforcing compliance[35].

In addition, the research incorporates environmental and scientific studies to assess the impact of crop residue burning on air quality, climate change, and public health. Reports and data from government agencies, such as the Central Pollution Control Board (CPCB), Indian Council of Agricultural Research (ICAR), and satellite-based monitoring systems, have been utilised to understand the magnitude, geographical distribution, and seasonal trends of stubble burning[36]. Scholarly articles, research papers, and institutional reports have further been referred to for analysing emissions, pollution levels, and health impacts[37].

The study also employs a critical and comparative analytical approach to evaluate the effectiveness of existing regulatory mechanisms and identify gaps in enforcement and policy implementation. It examines the interaction between legal provisions and ground-level realities, particularly the socio-economic constraints faced by farmers. While the primary focus remains on the Indian context, limited comparative references have been made to international practices where relevant, in order to highlight alternative approaches and best practices[38].

Furthermore, the methodology includes an interdisciplinary approach, integrating legal analysis with environmental science and agricultural economics. This approach enables a holistic understanding of the issue, recognising that crop residue burning is not merely a legal violation but a complex socio-economic and environmental problem.

However, the study is subject to certain limitations. It is based entirely on secondary data and does not include empirical field research or primary data collection. Additionally, while efforts have been made to incorporate recent developments, the dynamic nature of environmental policies and data may result in certain temporal limitations.

[35] Judicial Decisions and Environmental Law Reports
[36] CPCB, ICAR, and Government Reports on Stubble Burning
[37] Environmental and Scientific Research Studies (MDPI, Nature, etc.)
[38] Comparative Environmental Policy Studies

Overall, the adopted methodology is intended to provide a comprehensive, critical, and balanced analysis of crop residue burning in India, with a view to suggesting effective legal and policy reforms for sustainable environmental governance.

CHAPTER 4: LITERATURE REVIEW

The issue of crop residue burning in India has been widely examined across diverse fields such as environmental science, public health, agricultural economics, and policy studies. However, the existing body of literature reflects a fragmented approach, with limited integration of legal analysis into the broader discourse. The present review seeks to critically examine key scholarly contributions while identifying gaps that necessitate further research.

A substantial portion of the literature focuses on the environmental impact of crop residue burning, particularly its contribution to air pollution and climate change. Studies published in leading scientific journals highlight that stubble burning is a major source of particulate matter (PM2.5 and PM10), greenhouse gases, and other toxic emissions, significantly contributing to the deterioration of air quality in northern India. Research has demonstrated that during peak burning periods, the contribution of stubble burning to Delhi's air pollution can be considerable, thereby aggravating seasonal smog conditions[39]. These studies provide a strong empirical foundation for understanding the environmental severity of the issue.

Another significant strand of literature examines the public health implications of crop residue burning. Medical and environmental research has established a clear link between exposure to pollutants emitted from burning and an increase in respiratory and cardiovascular diseases, as well as premature mortality. Scholars have emphasised that the recurring nature of such

[39] Environmental Studies on Air Pollution (Nature, ScienceDirect)

pollution episodes transforms the issue into a public health emergency, particularly affecting vulnerable populations such as children and the elderly[40].

In addition, a considerable body of research explores the agricultural and socio-economic dimensions of crop residue burning. These studies attribute the persistence of the practice to factors such as the high cost of alternative technologies, lack of awareness, and the limited time available between cropping cycles. Research conducted by institutions such as the Indian Council of Agricultural Research (ICAR) highlights that farmers often perceive burning as the most economically viable option in the absence of adequate incentives and institutional support[41]. This literature is crucial in understanding the behavioural and economic drivers behind the practice.

Policy-oriented studies have also examined the role of government initiatives and technological interventions in addressing crop residue burning. These include analyses of schemes promoting machinery such as the Happy Seeder, bio-decomposition techniques, and crop diversification strategies. While such studies acknowledge the potential of these measures, they often point to challenges in large-scale adoption, including issues of accessibility, affordability, and implementation[42].

From a legal perspective, however, the literature remains relatively underdeveloped. While certain works on environmental law discuss the broader framework governing pollution control in India, including the Environment (Protection) Act, 1986 and the Air (Prevention and Control of Pollution) Act, 1981, there is limited focused analysis on their application to crop residue burning. Similarly, judicial interventions by the Supreme Court and the National Green Tribunal have been discussed in general environmental law literature, but their specific impact on regulating stubble burning has not been comprehensively evaluated[43].

Furthermore, there is a noticeable lack of interdisciplinary research that integrates legal, environmental, and socio-economic perspectives. Most studies tend to examine the issue in isolation, either as an environmental problem or an agricultural challenge, without adequately

[40] Public Health Research on Air Pollution Effects
[41] ICAR and Agricultural Economics Studies
[42] Policy and Technology Intervention Reports
[43] Environmental Law Literature and Judicial Analysis

addressing the complex interaction between law, policy, and ground-level realities. This gap limits the development of effective and holistic solutions.

In conclusion, while the existing literature provides valuable insights into the environmental, health, and economic aspects of crop residue burning, it reveals a significant gap in comprehensive legal analysis and interdisciplinary integration. The present study seeks to bridge this gap by critically examining the regulatory framework, enforcement challenges, and sustainable solutions within a unified analytical framework.

CHAPTER 5: LEGAL AND ETHICAL ANALYSIS

5.1 Adequacy and Effectiveness of the Legal and Regulatory Framework Governing Crop Residue Burning in India

The regulation of crop residue burning in India is situated within a broader framework of environmental governance that seeks to reconcile developmental imperatives with ecological sustainability. The legal architecture governing this issue is, in principle, both comprehensive and constitutionally grounded, deriving legitimacy from the expansive interpretation of the right to life under Article 21, which encompasses the right to a clean and healthy environment. Statutory enactments such as the Environment (Protection) Act, 1986 and the Air (Prevention and Control of Pollution) Act, 1981 confer wide-ranging powers upon regulatory authorities to prevent and control activities contributing to air pollution, including the open burning of agricultural waste. The establishment of specialised institutions such as the National Green Tribunal and the Commission for Air Quality Management (CAQM) further reflects an evolving and increasingly targeted regulatory response to the problem of air pollution in the National Capital Region (NCR) and adjoining areas[44].

Notwithstanding this seemingly robust legal framework, its practical efficacy remains deeply contested. A critical examination reveals a persistent disconnect between normative legal provisions and their actual implementation on the ground. While the statutory framework provides for prohibitory and penal measures against polluting activities, enforcement

[44] Environmental Law Framework (EPA, Air Act, CAQM Studies)

mechanisms suffer from systemic weaknesses, including inadequate monitoring, lack of realtime accountability, and inconsistent imposition of penalties. The rural and dispersed nature of agricultural burning further complicates enforcement, rendering traditional regulatory approaches insufficient. Consequently, the deterrent value of existing legal provisions is substantially diluted, allowing the practice to continue with relative impunity[45].

A further structural limitation lies in the fragmented and multi-layered nature of institutional governance. The regulation of crop residue burning involves a complex interplay between central and state governments, pollution control boards, agricultural departments, and local administrative authorities. This multiplicity of actors often results in overlapping jurisdictions, diffusion of responsibility, and lack of coordinated action. Despite the creation of bodies such as the CAQM to facilitate inter-state coordination, the effectiveness of such mechanisms is constrained by administrative inertia and uneven compliance across states. The absence of a harmonised and cohesive regulatory strategy significantly undermines the overall effectiveness of the legal framework[46].

Moreover, the prevailing regulatory approach is predominantly punitive in orientation, emphasising prohibition and penal sanctions as primary tools of enforcement. While such measures are essential for establishing legal accountability, they fail to adequately engage with the socio-economic realities that underpin the persistence of crop residue burning. Farmers, particularly small and marginal cultivators, operate within tight economic margins and face significant constraints, including high costs of residue management technologies, limited access to institutional support, and the exigencies of short cropping cycles. In this context, a purely coercive legal regime risks being both ineffective and inequitable, as it seeks to impose compliance without addressing the structural conditions that necessitate non-compliance[47].

Judicial intervention has emerged as a critical catalyst in shaping the discourse on crop residue burning and environmental governance more broadly. Courts have repeatedly underscored the gravity of the issue, framing it as a violation of fundamental rights and emphasising the need for stringent enforcement and administrative accountability. However, the efficacy of judicial directives is inherently contingent upon executive implementation. The recurrent need for

[45] Reports on Enforcement and Monitoring Gaps
[46] Studies on Institutional Coordination and Governance Issues
[47] Agricultural Economics and Farmer Constraint Studies

judicial intervention itself is indicative of systemic governance failures and highlights the limitations of a reactive, litigation-driven approach to environmental regulation[48].

In essence, the legal and regulatory framework governing crop residue burning in India is characterised by a paradox: it is normatively comprehensive yet operationally deficient. The persistence of the problem underscores the inadequacy of existing approaches that rely predominantly on prohibition and penalisation, without sufficient integration of economic incentives, technological solutions, and farmer-centric policies. Accordingly, there is an urgent need to reconceptualise the regulatory paradigm by adopting a more holistic and adaptive approach—one that harmonises legal enforcement with socio-economic realities, strengthens institutional coordination, and promotes sustainable agricultural practices. Such a transformation is essential not only for effective environmental governance but also for the realisation of the constitutional mandate of ensuring a clean and healthy environment.

5.2 Impact of Crop Residue Burning on Air Quality and Public Health in Northern India with Special Reference to the National Capital Region (NCR)

Crop residue burning has emerged as a critical contributor to the degradation of air quality in northern India, particularly in the National Capital Region (NCR), thereby transforming an agricultural practice into a significant environmental and public health crisis. The combustion of agricultural residues releases a complex mixture of pollutants, including fine particulate matter (PM2.5 and PM10), carbon monoxide, nitrogen oxides, sulphur dioxide, and volatile organic compounds. Among these, PM2.5 is especially hazardous due to its ability to penetrate deep into the respiratory system and enter the bloodstream, causing severe and long-term health effects. The scale and intensity of these emissions during peak burning periods substantially elevate ambient pollution levels, often pushing air quality into hazardous categories[49].

The impact of crop residue burning on air quality is further exacerbated by meteorological and geographical factors. During the post-monsoon and winter seasons, atmospheric conditions such as low wind speed, temperature inversion, and high humidity hinder the dispersion of pollutants, resulting in their accumulation over the Indo-Gangetic Plain. The geographical

[48] Judicial Observations on Environmental Enforcement
[49] Studies on Emissions from Crop Burning (MDPI, Environmental Research)

proximity of Punjab, Haryana, and western Uttar Pradesh to Delhi facilitates the transboundary movement of pollutants, thereby significantly influencing air quality in the NCR. Empirical studies and satellite data have consistently demonstrated that during peak burning periods, stubble burning can contribute substantially to Delhi's PM2.5 levels, at times accounting for as much as 30–35% of total pollution on certain days[50].

Beyond environmental degradation, the implications of crop residue burning for public health are profound and far-reaching. Prolonged exposure to elevated levels of air pollutants has been linked to a wide spectrum of health conditions, including respiratory illnesses such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD), as well as cardiovascular diseases and increased risk of stroke. The burden of these health impacts is disproportionately borne by vulnerable populations, including children, the elderly, and individuals with preexisting health conditions. Moreover, the recurrent nature of pollution episodes during peak burning seasons places sustained pressure on healthcare systems and contributes to increased morbidity and premature mortality[51].

The issue assumes greater significance when viewed through the lens of environmental justice and constitutional rights. The deterioration of air quality due to crop residue burning raises serious concerns regarding the violation of the fundamental right to life and a clean environment under Article 21. The inability to effectively control such pollution not only reflects environmental governance failures but also underscores the inequitable distribution of environmental harm, where urban populations bear the consequences of rural agricultural practices without corresponding accountability mechanisms[52].

Furthermore, the episodic yet recurrent nature of crop residue burning exacerbates its overall impact. Unlike continuous sources of pollution, stubble burning leads to sharp, seasonal spikes in pollution levels within short timeframes, thereby intensifying its adverse effects. These episodic surges often coincide with other pollution sources, such as vehicular emissions and industrial activities, creating a cumulative effect that pushes air quality to critical levels. The predictability of these seasonal patterns, however, also highlights a significant policy failure,

[50] Data on PM2.5 Contribution and Satellite Studies (ScienceDirect, Government Reports)
[51] Public Health Research on Air Pollution (WHO, Medical Journals)
[52] Constitutional and Environmental Law Studies (Article 21 Interpretation)

as preventive and pre-emptive measures remain inadequate despite recurring evidence of the problem[53].

In essence, crop residue burning constitutes a major and quantifiable source of air pollution in northern India, with severe implications for environmental quality and public health. Its impact is magnified by meteorological conditions, geographical proximity, and the cumulative effect of other pollution sources. Addressing this issue, therefore, requires not only regulatory intervention but also a comprehensive understanding of its environmental, health, and socioeconomic dimensions. A failure to effectively mitigate this practice undermines both environmental sustainability and the constitutional mandate of ensuring a healthy living environment for all.

5.3 Structural and Institutional Deficiencies in the Enforcement of Laws Regulating Crop Residue Burning in India

The regulation of crop residue burning in India is marked by a significant disconnect between the existence of a comprehensive legal framework and its effective enforcement on the ground. While statutory provisions under the Environment (Protection) Act, 1986 and the Air (Prevention and Control of Pollution) Act, 1981 provide a strong legal basis for controlling air pollution, the persistence of large-scale stubble burning reveals deep-rooted structural and institutional deficiencies within the enforcement mechanism. These deficiencies are not merely incidental but systemic, reflecting limitations in governance, coordination, and accountability.

At the statutory level, Section 3 of the Environment (Protection) Act, 1986 empowers the Central Government to take all necessary measures to protect and improve environmental quality, including the regulation of activities causing pollution. Further, Section 5 authorises the issuance of directions, including the closure or regulation of any industry or process contributing to environmental harm. Similarly, under the Air Act, Section 19 allows state governments to declare air pollution control areas, while Sections 21 and 22 regulate emissions and prohibit the discharge of pollutants beyond prescribed standards. In addition, Section 31A empowers pollution control boards to issue binding directions. Despite these extensive powers,

[53] Research on Seasonal Pollution Trends and Combined Sources

enforcement remains inconsistent and often ineffective, particularly in rural and agrarian contexts where monitoring is difficult and administrative reach is limited[54]

A primary structural deficiency lies in the inadequacy of monitoring and enforcement mechanisms. Crop residue burning typically occurs across vast and dispersed agricultural fields, making real-time detection and enforcement challenging. Although satellite-based monitoring has improved identification of fire incidents, the translation of such data into legal action remains weak. Penalties imposed on violators are often nominal, inconsistently applied, or politically contested, thereby diminishing their deterrent value. This results in a regulatory regime that exists largely in form rather than in substance[55].

Another critical issue is the fragmentation of institutional responsibility. The governance of crop residue burning involves multiple agencies, including central ministries, state governments, State Pollution Control Boards (SPCBs), agricultural departments, and local administrative bodies. This multiplicity of actors leads to overlapping jurisdictions and diffusion of accountability, often resulting in administrative inertia. The establishment of the Commission for Air Quality Management Act, 2021 was intended to address this issue by creating a centralised authority with powers of coordination and enforcement in the NCR and adjoining areas. However, the effectiveness of this body is contingent upon cooperation from state authorities, which has been uneven in practice[56].

Judicial intervention has repeatedly highlighted these enforcement failures. In In Re: Air Pollution (Stubble Burning Cases),[57] the Supreme Court expressed serious concern over the continued incidence of stubble burning despite existing legal prohibitions, emphasising that the right to a clean environment forms an integral part of Article 21. The Court criticised state authorities for their lack of effective action and underscored the need for accountability in enforcement. Similarly, in M.C. Mehta v. Union of India,[58] the Court laid down foundational principles of environmental governance, including the necessity of strict enforcement of pollution control laws and the responsibility of the State to ensure environmental protection.

[54] Environment (Protection) Act, 1986; Air Act, 1981 – Sections Analysis
[55] Reports on Monitoring and Enforcement Gaps (CPCB, Satellite Data Studies)
[56] CAQM Act and Institutional Coordination Reports
[57] Supreme Court: *In Re: Air Pollution (Stubble Burning Cases)*
[58] M.C. Mehta v. Union of India

Further, in Vellore Citizens Welfare Forum v. Union of India[59], the Supreme Court introduced the Precautionary Principle and Polluter Pays Principle as essential components of environmental law in India. These principles impose a duty on the State to prevent environmental harm even in the absence of scientific certainty and to ensure that those responsible for pollution bear the cost of remediation. However, the continued prevalence of crop residue burning indicates a failure to effectively operationalise these principles in practice. The decision in Subhash Kumar v. State of Bihar[60] further reinforced that the right to pollution-free air is a fundamental right under Article 21, thereby imposing a constitutional obligation on the State to prevent environmental degradation.

Despite such strong judicial pronouncements, enforcement remains weak due to limited administrative capacity, lack of political will, and socio-economic constraints. Courts have, on multiple occasions, directed state governments to take stringent action, including the imposition of penalties and the adoption of preventive measures. However, the recurring need for judicial intervention itself reflects the inability of executive authorities to independently ensure compliance.

In addition, the enforcement framework is undermined by a disconnect between legal mandates and ground-level realities. Farmers often lack access to affordable alternatives to burning, and enforcement actions against them may lead to resistance or non-compliance. This highlights the limitations of a purely coercive approach, which fails to address the underlying causes of the problem.

In conclusion, the enforcement of laws regulating crop residue burning in India is characterised by systemic deficiencies, including weak monitoring mechanisms, fragmented institutional structures, and inadequate implementation of statutory provisions and judicial directives. While the legal framework is robust in theory, its effectiveness is significantly compromised in practice. Addressing these deficiencies requires not only strengthening enforcement mechanisms but also ensuring better coordination among institutions, enhancing administrative accountability, and aligning legal measures with socio-economic realities.

[59] Vellore Citizens Welfare Forum v. Union of India
[60] Subhash Kumar v. State of Bihar

5.4 Socio-Economic and Structural Determinants Influencing Farmers' Continued Reliance on Crop Residue Burning and Their Implications for Legal Compliance

The persistence of crop residue burning in India cannot be fully understood through a purely legal lens; rather, it is deeply embedded in the socio-economic and structural realities of the agrarian sector. While statutory prohibitions exist under the Environment (Protection) Act, 1986 and the Air (Prevention and Control of Pollution) Act, 1981, the continued prevalence of stubble burning reflects the limited capacity of law to secure compliance in the absence of viable economic and technological alternatives. This underscores a fundamental tension between environmental regulation and agrarian livelihood, necessitating a nuanced and context-sensitive regulatory approach.

At the core of the issue lies the economic vulnerability of farmers, particularly small and marginal cultivators, who operate under tight financial constraints. The adoption of sustainable residue management technologies—such as the Happy Seeder or Super Straw Management Systems—entails significant capital investment, which is often beyond the reach of farmers without substantial state support. Although Section 3 of the Environment (Protection) Act, 1986 empowers the government to take measures for environmental protection, including the promotion of sustainable practices, the implementation of such measures has been uneven and insufficient. Consequently, burning remains the most cost-effective and time-efficient method for residue disposal[61].

Another critical factor is the structural rigidity of the rice–wheat cropping cycle, particularly in states such as Punjab and Haryana. The narrow window between harvesting and sowing—often limited to two to three weeks—creates immense time pressure on farmers, leaving little scope for alternative residue management practices. In such circumstances, the legal prohibition under Section 22 of the Air (Prevention and Control of Pollution) Act, 1981, which restricts the emission of pollutants beyond prescribed standards, becomes difficult to enforce in practice. The law, while normatively sound, fails to adequately accommodate the temporal and operational constraints inherent in agricultural production systems[62].

[61] EPA, 1986 – Section 3 and Policy Implementation Studies
[62] Air Act, 1981 – Section 22 and Agricultural Constraints Studies

The issue is further compounded by limited access to institutional support and awareness mechanisms. While government schemes and subsidies exist to promote alternative technologies, their reach and effectiveness remain inconsistent. Administrative inefficiencies, lack of awareness among farmers, and delays in the disbursement of financial assistance reduce the uptake of such measures. This creates a gap between policy formulation and actual implementation, thereby undermining the objectives of environmental regulation[63].

Judicial pronouncements have recognised the need to balance environmental protection with socio-economic realities. In M.C. Mehta v. Union of India, the Supreme Court emphasised that environmental measures must be practical and enforceable, taking into account groundlevel realities. Similarly, in Vellore Citizens Welfare Forum v. Union of India, while affirming the Precautionary Principle and Polluter Pays Principle, the Court also highlighted the importance of sustainable development, which requires a balance between environmental protection and economic development. These principles imply that regulatory measures must not disproportionately burden economically weaker sections, including farmers.

In Subhash Kumar v. State of Bihar, the Court recognised the right to a pollution-free environment as a fundamental right under Article 21. However, the enforcement of this right in the context of crop residue burning raises complex questions of distributive justice, as the costs of compliance are borne by farmers, while the benefits of cleaner air accrue more broadly to society. This imbalance necessitates a more equitable regulatory framework that incorporates financial assistance and technological support as integral components of compliance[64].

Further, in the ongoing proceedings relating to In Re: Air Pollution (Stubble Burning Cases), the Supreme Court has acknowledged that penalising farmers alone is not a sustainable solution and has emphasised the need for state support mechanisms, including subsidies and policy interventions. This reflects a judicial recognition of the socio-economic dimensions of the problem and the limitations of a purely punitive approach[65].

[63] ICAR and Government Reports on Farmer Support Schemes
[64] *Subhash Kumar v. State of Bihar* – Right to Clean Environment
[65] Supreme Court: *In Re: Air Pollution (Stubble Burning Cases)*

The continued reliance on crop residue burning, therefore, highlights a misalignment between legal mandates and socio-economic realities. Laws that impose strict liability without providing feasible alternatives risk non-compliance and resistance. The absence of an integrated approach that combines legal enforcement with economic incentives, technological accessibility, and institutional support further exacerbates the problem.

In conclusion, the socio-economic determinants of crop residue burning play a decisive role in shaping farmer behaviour and compliance with environmental laws. The persistence of the practice underscores the inadequacy of regulatory approaches that fail to account for these realities. A sustainable solution requires a paradigm shift from a coercive, penalty-driven framework to a more balanced and inclusive model that integrates legal regulation with economic support, technological innovation, and farmer-centric policies. Such an approach is essential to ensure both environmental protection and agrarian sustainability, in line with the broader objectives of sustainable development and constitutional governance.

5.5 Evaluating the Efficacy of Punitive Measures vis-à-vis Incentive-Based Regulatory Approaches in Controlling Crop Residue Burning in India

The regulatory response to crop residue burning in India has traditionally been characterised by a predominantly punitive approach, grounded in statutory prohibitions and penal sanctions. However, the persistent recurrence of the practice raises fundamental questions regarding the efficacy of such coercive measures in achieving environmental compliance. A critical evaluation reveals that while punitive provisions are essential for establishing legal accountability, their effectiveness remains limited in the absence of complementary incentivebased mechanisms that address the underlying socio-economic drivers of the problem.

Under the Environment (Protection) Act, 1986, Section 15 prescribes penalties for contravention of its provisions, including imprisonment and fines for acts that result in environmental pollution. Similarly, the Air (Prevention and Control of Pollution) Act, 1981 provides for penal consequences under Section 37, which imposes punishment for failure to comply with the directions of pollution control authorities. In addition, Section 31A empowers Pollution Control Boards to issue binding directions, including the prohibition of polluting activities such as open burning. While these provisions establish a strong legal deterrent in

theory, their application in the context of crop residue burning has been inconsistent and often ineffective due to enforcement challenges and socio-political considerations[66].

The limitations of a purely punitive approach are particularly evident when viewed against the socio-economic realities of the agricultural sector. Farmers, especially small and marginal landholders, often lack the financial capacity to adopt alternative residue management technologies. In such circumstances, the imposition of penalties may not only fail to deter the practice but may also exacerbate economic distress, leading to resistance and non-compliance. This highlights the inherent inadequacy of a coercive framework that seeks to enforce environmental norms without addressing structural constraints[67].

Judicial discourse in India has increasingly recognised the need for a more balanced regulatory approach. In Rural Litigation and Entitlement Kendra v. State of Uttar Pradesh,[68] the Supreme Court underscored the importance of environmental protection while simultaneously acknowledging the socio-economic implications of regulatory measures. The Court emphasised that environmental governance must be informed by considerations of equity and sustainability, rather than relying solely on punitive enforcement.

Similarly, in Indian Council for Enviro-Legal Action v. Union of India,[69] the Court reinforced the Polluter Pays Principle, holding that those responsible for environmental harm must bear the cost of remediation. However, the application of this principle in the context of crop residue burning raises complex questions, as farmers—often economically vulnerable—may not be in a position to bear such costs. This necessitates a nuanced application of the principle, wherein the State assumes a supportive role in facilitating compliance through financial and technological assistance.

Further, in Narmada Bachao Andolan v. Union of India,[70] the Supreme Court elaborated upon the doctrine of sustainable development, emphasising the need to balance environmental

[66] EPA, 1986 – Section 15; Air Act, 1981 – Sections 31A & 37
[67] Studies on Socio-economic Constraints and Enforcement Limits
[68] Indian Council for Enviro-Legal Action v. Union of India
[69] Rural Litigation and Entitlement Kendra v. State of Uttar Pradesh

[70] *Narmada Bachao Andolan v. Union of India*

protection with developmental and economic considerations. This principle is particularly relevant in the context of crop residue burning, where regulatory measures must reconcile ecological imperatives with the livelihood concerns of farmers.

The inadequacy of punitive measures has led to an increasing emphasis on incentive-based regulatory approaches, which aim to promote voluntary compliance through economic and technological support. Government initiatives providing subsidies for machinery such as the Happy Seeder, financial assistance for residue management, and promotion of biodecomposition techniques represent steps in this direction. Such measures seek to internalise environmental objectives within agricultural practices by making sustainable alternatives economically viable for farmers[71].

Moreover, the Commission for Air Quality Management Act, 2021 reflects a shift towards a more coordinated and policy-oriented approach, enabling the formulation of strategies that combine enforcement with incentives and inter-state collaboration. This indicates an evolving regulatory paradigm that recognises the limitations of coercive measures and the need for integrated solutions.

In conclusion, while punitive provisions remain an essential component of environmental regulation, their standalone application is insufficient to effectively address the complex issue of crop residue burning. A sustainable and effective regulatory framework must adopt a hybrid approach, combining deterrence with incentives, technological innovation, and institutional support. Such a model not only enhances compliance but also aligns environmental objectives with socio-economic realities, thereby advancing the broader goals of sustainable development and equitable environmental governance.

5.6 Role and Effectiveness of Judicial Intervention in Addressing Crop Residue Burning and Strengthening Environmental Governance in India

Judicial intervention has played a transformative role in the evolution of environmental governance in India, particularly in contexts where executive inaction and regulatory inefficiencies have undermined the implementation of environmental laws. In the specific context of crop residue burning, the judiciary—especially the Supreme Court and the National

[71] Government Policy Reports on Incentive Schemes (Happy Seeder, etc.)

Green Tribunal (NGT)—has emerged as a crucial institutional actor in highlighting the gravity of the issue, enforcing accountability, and shaping policy responses. However, while judicial activism has significantly contributed to norm-setting and awareness, its effectiveness remains contingent upon administrative compliance and institutional capacity.

The constitutional foundation of judicial intervention in environmental matters lies in the expansive interpretation of Article 21, which guarantees the right to life and has been judicially extended to include the right to a clean and healthy environment. This constitutional mandate has enabled courts to exercise wide powers under Articles 32 and 226 to issue directions, enforce fundamental rights, and compel governmental authorities to act in cases of environmental degradation. Additionally, statutory frameworks such as the National Green Tribunal Act, 2010—particularly Sections 14 and 15—empower the NGT to adjudicate environmental disputes and grant relief, compensation, and restitution for environmental damage[72].

In the context of crop residue burning, the NGT has been particularly proactive. In Original Application No. 606/2018 (Compliance of Municipal Solid Waste Rules), the Tribunal issued directions imposing environmental compensation on farmers engaging in stubble burning, as well as on state authorities for failure to prevent such incidents. The NGT emphasised the principle of strict liability and underscored the responsibility of state governments to implement preventive measures, including awareness programmes and provision of alternative technologies. These directions reflect an attempt to operationalise environmental principles through enforceable mandates[73].

The Supreme Court has also played a pivotal role in advancing environmental jurisprudence relevant to air pollution. In A.P. Pollution Control Board v. Prof. M.V. Nayudu, the Court elaborated upon the Precautionary Principle, emphasising that environmental measures must anticipate, prevent, and attack the causes of environmental degradation even in the absence of complete scientific certainty. This principle is particularly relevant to crop residue burning, where the cumulative impact of emissions necessitates preventive regulatory action rather than reactive enforcement.

[72] NGT Act, 2010 – Sections 14 & 15; Constitutional Provisions (Articles 21, 32, 226)
[73] NGT Orders on Stubble Burning (O.A. No. 606/2018)

Similarly, in Murli S. Deora v. Union of India, the Supreme Court recognised the harmful effects of air pollution on public health and imposed restrictions on smoking in public places. Although not directly related to crop residue burning, the case is significant in establishing judicial willingness to intervene in matters affecting air quality and public health, thereby reinforcing the broader framework within which stubble burning is addressed[74].

Further, in Sachidanand Pandey v. State of West Bengal,[75] the Court emphasised that environmental considerations must be integrated into decision-making processes and that courts have a duty to ensure that ecological balance is maintained. This principle underscores the judiciary's role in ensuring that environmental concerns are not subordinated to economic or administrative convenience.

Despite these significant contributions, the effectiveness of judicial intervention remains inherently limited. Courts primarily function as adjudicatory bodies and rely on executive agencies for implementation of their directives. In the case of crop residue burning, repeated judicial directions have often been met with partial or inconsistent compliance, reflecting systemic governance challenges. The judiciary's role, therefore, tends to be reactive and supervisory, rather than preventive or administrative. The recurrence of litigation and repeated court interventions indicate that judicial activism, while necessary, cannot substitute for effective policy implementation and administrative action[76].

Moreover, excessive reliance on judicial intervention risks overburdening the courts and blurring the separation of powers, as courts are compelled to step into domains traditionally reserved for the executive. While judicial oversight is essential for ensuring accountability, sustainable solutions to crop residue burning require proactive governance, coordinated policy measures, and institutional strengthening beyond the courtroom.

[74] *Murli S. Deora v. Union of India*
[75] Sachidanand Pandey v. State of West Bengal
[76] A.P. Pollution Control Board v. Prof. M.V. Nayudu

ANALYSIS AND DISCUSSION

The issue of crop residue burning in India reflects a complex intersection of environmental degradation, legal inadequacy, and socio-economic compulsion. A critical analysis of the existing framework reveals that while India possesses a relatively comprehensive set of environmental laws, the persistence of stubble burning exposes a fundamental disconnect between legal norms and ground-level realities. This gap is not merely a failure of law but a manifestation of deeper structural, institutional, and policy-related challenges.

From a legal standpoint, the framework appears robust in design, with clear statutory prohibitions against activities that contribute to air pollution. However, the effectiveness of these provisions is significantly undermined by weak enforcement and lack of accountability. Regulatory authorities often face practical difficulties in monitoring large-scale, dispersed agricultural activities, which limits their ability to detect and penalise violations in real time. Moreover, the enforcement process is frequently influenced by political and administrative considerations, leading to inconsistent application of penalties. As a result, the deterrent value of the law is substantially diluted, allowing the practice to continue despite formal prohibitions.

A deeper analysis indicates that the problem is not solely legal but fundamentally structural in nature. The agricultural system in northern India, particularly the rice–wheat cropping cycle, creates conditions that indirectly incentivise burning. Farmers operate within extremely narrow time windows between harvesting and sowing, leaving them with limited options for residue management. In this context, burning becomes the most efficient and economically viable method, regardless of its environmental consequences. The law, in its current form, fails to adequately account for these structural constraints, thereby rendering compliance both difficult and, in many cases, impractical.

The socio-economic dimension further complicates the issue. A significant proportion of farmers lack the financial capacity to invest in alternative technologies or practices. While government schemes and subsidies exist, their accessibility and effectiveness remain uneven. The regulatory approach, which largely relies on penal measures, tends to overlook these economic realities. This creates a situation where compliance is not just a matter of willingness but of capability. Penalising farmers without addressing these underlying constraints risks alienating stakeholders and undermining the legitimacy of the regulatory framework.

Institutional fragmentation also emerges as a critical factor affecting the effectiveness of regulation. The multiplicity of agencies involved in addressing crop residue burning often leads to overlapping responsibilities and lack of coordination. This diffusion of accountability results in administrative inefficiencies and delays in implementation. Even when policies are formulated at the central level, their execution at the state and local levels remains inconsistent, reflecting gaps in governance and institutional capacity.

Judicial intervention has undoubtedly played a significant role in bringing attention to the issue and reinforcing the importance of environmental protection. Courts have repeatedly emphasised the need for strict enforcement and have framed the issue within the broader context of fundamental rights. However, judicial action, by its very nature, is reactive and dependent on executive compliance. The repeated need for court intervention indicates systemic weaknesses in governance and highlights the limitations of relying on litigation as a primary tool for environmental regulation.

Another important aspect that emerges from the analysis is the inadequacy of a purely punitive regulatory model. While penalties are necessary to establish accountability, they are insufficient to address a problem that is deeply rooted in economic and structural realities. A more effective approach would involve a combination of deterrence and incentives, supported by technological innovation and institutional support. The gradual shift towards promoting sustainable alternatives, such as residue management technologies and crop diversification, reflects a recognition of this need. However, the scale and pace of implementation remain inadequate to produce meaningful change.

The environmental and public health implications of crop residue burning further underscore the urgency of addressing the issue. The seasonal spikes in air pollution not only degrade environmental quality but also impose significant health and economic costs on society. These impacts are not confined to the regions where burning occurs but extend to urban centres, highlighting the transboundary nature of the problem. This necessitates a coordinated and integrated approach that goes beyond state-level interventions.

In conclusion, the problem of crop residue burning in India cannot be effectively addressed through legal regulation alone. It requires a holistic and multidimensional approach that integrates legal enforcement with economic incentives, technological solutions, and institutional coordination. The existing framework, while comprehensive in theory, falls short in practice due to its inability to align with ground realities. Addressing this gap is essential for achieving sustainable environmental governance and ensuring a balance between ecological protection and agricultural sustainability.

FINDINGS AND OBSERVATIONS

The study reveals that crop residue burning in India is not merely an environmental issue but a multidimensional governance challenge involving legal, institutional, economic, and technological factors. The following key findings and observations emerge from the analysis:

1. Legal Framework is Comprehensive but Ineffective in Practice - It is observed that India possesses a well-developed legal framework for environmental protection, with clear statutory provisions addressing air pollution. However, the persistence of crop residue burning indicates that these laws are largely ineffective at the implementation level. The gap between legal provisions and ground realities significantly weakens the regulatory impact.

2. Enforcement Mechanisms are Weak and Inconsistent - A major finding is the inadequacy of enforcement mechanisms, particularly in rural and agricultural regions. Monitoring challenges, lack of real-time accountability, and inconsistent imposition of penalties reduce the deterrent effect of laws. Enforcement often appears reactive rather than preventive, allowing the problem to recur seasonally.

3. Institutional Fragmentation Undermines Governance - The study highlights that multiple authorities with overlapping jurisdictions lead to diffusion of responsibility and lack of coordinated action. This institutional fragmentation results in inefficiencies, delayed responses, and weak accountability, thereby undermining the overall effectiveness of regulatory measures.

4. Socio-Economic Constraints Drive Non-Compliance - One of the most significant observations is that farmers' continued reliance on crop residue burning is primarily driven by economic and structural compulsions rather than deliberate non-compliance. High costs of alternative technologies, limited access to resources, and narrow cropping cycles make burning the most feasible option for many farmers.

5. Punitive Approach Alone is Insufficient - The study finds that a penalty-driven regulatory approach is inadequate to address the issue. While legal sanctions are necessary, they fail to achieve desired results when not supported by viable alternatives and incentives.

Excessive reliance on punitive measures may also lead to resistance and reduced cooperation from farmers.

6. Limited Effectiveness of Policy Implementation - Although several government schemes and technological solutions have been introduced, their implementation remains uneven and insufficient in scale. Issues such as lack of awareness, administrative delays, and limited accessibility hinder the widespread adoption of sustainable alternatives.

7. Judicial Intervention has Raised Awareness but not Ensured Compliance

Judicial intervention has played a critical role in recognising the seriousness of the issue and reinforcing environmental accountability. However, the study observes that judicial directions alone have not translated into consistent on-ground compliance, due to limitations in executive enforcement and administrative capacity.

8. Seasonal and Transboundary Nature Intensifies the Problem - Crop residue burning is characterised by seasonal spikes and cross-regional impacts, particularly affecting air quality in the National Capital Region. This highlights the need for coordinated inter-state action, which is currently inadequate.

9. Environmental and Public Health Impacts are Severe and Recurring - The findings confirm that crop residue burning significantly contributes to air pollution, smog formation, and adverse health outcomes, including respiratory and cardiovascular diseases. The recurring nature of these impacts makes the issue a persistent public health concern.

10. Lack of Integrated and Holistic Approach - A key observation is the absence of a comprehensive, integrated strategy that combines legal regulation, economic incentives, technological support, and institutional coordination. Existing efforts remain fragmented and insufficient to address the root causes of the problem.

SUGGESTIONS AND RECOMMENDATIONS

In light of the findings, it is evident that addressing crop residue burning in India requires a comprehensive, multi-dimensional, and pragmatic approach that goes beyond conventional legal enforcement. The following recommendations are proposed to ensure an effective and sustainable solution:

1. Shift from Punitive to Balanced Regulatory Approach

The regulatory framework should move beyond a predominantly penalty-based system and adopt a hybrid model that combines enforcement with incentives. While legal sanctions must continue to act as a deterrent, equal emphasis should be placed on enabling compliance through supportive measures.

2. Strengthening Enforcement and Monitoring Mechanisms

There is a need to enhance real-time monitoring and accountability through the use of advanced technologies such as satellite imaging, remote sensing, and digital reporting systems. Enforcement agencies should be empowered with better infrastructure, trained personnel, and clear protocols to ensure consistent implementation of laws.

3. Enhancing Institutional Coordination

Effective regulation requires greater coordination among central, state, and local authorities. A unified and streamlined institutional framework should be developed to reduce overlaps and ensure clear allocation of responsibilities. Regular inter-state coordination mechanisms should be institutionalised to address the transboundary nature of the problem.

4. Promoting Affordable and Accessible Alternatives

The government must ensure that sustainable residue management technologies are affordable, accessible, and widely available to farmers. This includes increasing subsidies, facilitating easy access to machinery through custom hiring centres, and promoting cooperative models for shared use of equipment.

5. Expanding Financial Incentives and Support Mechanisms

Direct financial assistance, such as cash incentives, subsidies, and compensation schemes, should be provided to farmers who adopt environmentally sustainable practices. Timely disbursement of funds and simplification of procedures are essential to ensure effective utilisation.

6. Encouraging Crop Diversification

Long-term solutions should focus on reducing dependence on the rice–wheat cropping cycle, particularly in water-stressed regions. Promoting alternative crops through assured procurement, price support, and market linkages can help reduce the generation of excess residue.

7. Capacity Building and Awareness Generation

There is a need for extensive awareness campaigns and training programmes to educate farmers about the environmental and health impacts of stubble burning, as well as the benefits of alternative practices. Extension services should play a proactive role in bridging the knowledge gap.

8. Strengthening Policy Implementation and Accountability

Policies must be backed by clear implementation frameworks, measurable targets, and accountability mechanisms. Regular audits, performance reviews, and transparent reporting systems should be introduced to ensure that policy objectives are effectively achieved.

9. Promoting Research and Innovation

Investment in research and development should be increased to identify cost-effective and scalable solutions for residue management. Innovations such as bio-decomposition, biomass energy utilisation, and conversion of agricultural waste into commercial products should be encouraged.

10. Adopting a Regional and Integrated Approach

Given the transboundary nature of air pollution, a regional strategy involving all affected states is essential. Policies should be harmonised across states, and joint action plans should be implemented to ensure coordinated efforts in controlling crop residue burning.

11. Integrating Environmental and Agricultural Policies

Environmental objectives must be mainstreamed into agricultural policy planning. This includes aligning subsidies, procurement policies, and agricultural incentives with sustainable practices to ensure long-term behavioural change among farmers.

12. Encouraging Public-Private Participation

Private sector participation should be promoted in areas such as technology development, waste management, and biomass utilisation. Public-private partnerships can play a significant role in scaling up sustainable solutions and creating economic value from agricultural waste.

CONCLUSION

Crop residue burning in India represents a critical environmental and governance challenge that transcends the boundaries of law, agriculture, and public health. The study demonstrates that although India has developed a comprehensive legal framework aimed at controlling air pollution and protecting environmental quality, the persistence of stubble burning reflects a significant gap between legal intent and practical implementation. This disconnect is not merely a failure of statutory provisions but is deeply rooted in structural, institutional, and socio-economic realities.

The analysis reveals that the existing regulatory approach, which relies heavily on punitive measures, is insufficient to address a problem that is fundamentally driven by economic necessity and agricultural constraints. Farmers, particularly small and marginal cultivators, often resort to burning not out of disregard for the law, but due to limited alternatives, financial pressures, and the rigid timelines imposed by cropping cycles. In such a context, legal prohibitions without adequate support mechanisms risk being ineffective and, at times, counterproductive.

Judicial intervention has played an important role in elevating the issue within the framework of constitutional rights and environmental governance. Courts have consistently emphasised the importance of a clean and healthy environment and have sought to enforce accountability among state authorities. However, the recurring nature of the problem indicates that judicial directions alone cannot ensure compliance in the absence of strong administrative will and effective policy execution.

The study also highlights the fragmented nature of institutional governance and the lack of coordinated action among various stakeholders. The transboundary character of air pollution further complicates the issue, requiring a unified and regionally coordinated response. While

recent policy initiatives and technological interventions indicate a shift towards more sustainable solutions, their impact remains limited due to challenges in accessibility, awareness, and implementation.

Ultimately, the problem of crop residue burning underscores the need for a paradigm shift in regulatory strategy. A sustainable solution lies in adopting a holistic approach that integrates legal enforcement with economic incentives, technological innovation, and farmer-centric policies. Environmental regulation must move beyond coercion and evolve into a facilitative framework that enables compliance by addressing the root causes of the problem.

In conclusion, the effective regulation of crop residue burning requires not only stronger laws but also better governance, inclusive policymaking, and sustained institutional commitment. Achieving a balance between environmental protection and agricultural sustainability is essential for ensuring long-term ecological security and safeguarding public health. Only through a coordinated, adaptive, and equitable approach can this persistent challenge be meaningfully addressed.

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