Monaldi Archives for Chest Disease

Monaldi Archives for Chest Disease 2026; 96:3937
doi: 10.4081/monaldi.2026.3937

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Preventable yet persistent: silicosis and gaps in public health policy – a narrative review

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Abstract

Silicosis remains a critical, 100% preventable occupational lung disease that continues to persist as a global public health crisis in the 21st century. Despite decades of industrial safety knowledge, the disease is currently seeing a modern resurgence, particularly in the engineered stone industry, where high-intensity silica exposure leads to rapid, fatal disease variants. This review synthesizes current global and national evidence to highlight the staggering burden of silicosis, with a specific focus on India, where over 50 million workers are projected to be at risk by 2026. Epidemiological data from high-risk clusters in Rajasthan and Gujarat reveal localized prevalence rates as high as 69%, often complicated by a devastating "syndemic" of silicosis and tuberculosis. The persistence of this disease is fundamentally attributed to an "implementation gap" in occupational health policy, characterized by weak enforcement in the informal sector, the invisibility of migrant labor and diagnostic failures. While engineering controls and medical surveillance are established gold standards, their adoption remains inconsistent in low-resource settings. This review advocates for a transition toward a rights-based accountability model, mandatory digital reporting, and the integration of occupational health into broader public health strategies. Ultimately, eliminating silicosis requires moving beyond clinical observation toward robust inter-ministerial coordination and strict legal liability for workplace safety failures.

Key words: silicosis, occupational health, public health policy, India, preventive medicine.

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Introduction

Silicosis is a chronic, fibrotic occupational lung disease resulting from the inhalation of respirable crystalline silica (RCS). RCS particles, typically less than 5 micrometers in diameter, penetrate deep into the alveolar regions of the lungs, triggering a persistent inflammatory response and subsequent nodular fibrosis [1]. It is one of the oldest recognized occupational diseases, yet it continues to persist globally despite decades of scientific evidence demonstrating that it is entirely preventable through effective exposure control measures, engineering interventions, and regulatory enforcement [2].

Exposure to crystalline silica occurs across a wide range of industries, including mining, quarrying, construction, stone cutting, ceramics, foundries, and sandblasting. In recent years, outbreaks of accelerated and acute silicosis among workers engaged in engineered stone fabrication have drawn global attention, demonstrating that silicosis is not merely a legacy disease but also an emerging occupational hazard associated with modern industrial practices [3]. These outbreaks have reinforced concerns that existing regulatory frameworks have not kept pace with changing industrial exposures. Despite being a disease that has been medically recognized for centuries, silicosis remains a silent epidemic in the 21st century. It is characterized by its progressive nature; even after exposure ceases, the pulmonary damage often continues to worsen, leading to severe respiratory failure, increased susceptibility to tuberculosis (TB) (silico-TB), and lung cancer [4].

Currently, there is no curative treatment for silicosis, and clinical management is largely supportive, focusing on symptom relief, prevention of complications, and elimination of further exposure [5]. This lack of effective treatment further emphasizes the necessity of prevention as the fundamental aspect of silicosis control. India bears a substantial burden of silicosis, particularly among workers in mining, stone crushing, agate polishing, slate pencil manufacturing, and construction sectors [6]. Evidence from Indian studies highlights persistent gaps in awareness, surveillance, regulatory enforcement, and access to compensation, despite the existence of occupational safety legislation. The absence of a comprehensive national silicosis control and surveillance program has further contributed to fragmented prevention efforts and delayed diagnosis, allowing the disease to remain entrenched in vulnerable populations. In developing economies, a vast majority of the at-risk workforce is employed in the unorganized sector, small-scale mining (SSM), agate polishing, and construction, where safety regulations

are seldom enforced, and workers lack formal employment contracts. Beyond its direct respiratory effects, silicosis has broader public health implications due to its strong association with TB, particularly in high TB-burden countries such as India [7]. In addition, silicosis is associated with an increased risk of chronic obstructive pulmonary disease, lung cancer, and autoimmune disorders, further amplifying its long-term health and socioeconomic burden [8].

From a public health perspective, silicosis is considered 100% preventable. The hierarchy of controls, ranging from the engineering of the wet-method processing and local exhaust ventilation (LEV) to the provision of high-efficiency respiratory protection, is well-established in industrial hygiene. When these primary prevention strategies are strictly adhered to, the incidence of the disease is negligible. For instance, high-income countries saw a drastic decline in silicosis cases during the mid-20th century due to robust regulatory oversight and the mechanization of safety protocols [9].

Despite these known solutions, the disease persists due to a complex interplay of economic and industrial shifts. A modern resurgence of accelerated silicosis has been documented globally among workers manufacturing artificial quartz countertops, which contain significantly higher silica concentrations (>90%) compared to natural stone (20-30%) [10].

This narrative review was conducted to address the urgent public health necessity of bridging the persistent gap between established preventive measures and the modern resurgence of silicosis in both informal sectors and emerging high-tech industries. A systematic search strategy was employed across electronic databases, including PubMed, Google Scholar, and Cochrane Library, using primary keywords such as "silicosis", "occupational exposure", "public health policy", and "silico-tuberculosis". The search was focused on peer-reviewed literature and institutional reports published primarily between 2019 and 2025 to capture the most recent industrial outbreaks, such as those in the engineered stone sector, and current shifts in regulatory frameworks. Inclusion criteria were restricted to studies providing quantitative data on disease burden, biological mechanisms of fibrosis, or evaluations of public health interventions, while studies with non-verifiable data or those focused solely on non-occupational silica exposure were excluded. By synthesizing this recent evidence with an analysis of implementation failures, this review aims to provide actionable recommendations for integrated occupational safety and healthcare frameworks.

Overview of silicosis: pathophysiology and policy implications

Silicosis is a multifaceted occupational health crisis, categorized not merely by the presence of scarring, but by the tempo of disease progression relative to dust concentration. In the context of public health policy, these classifications serve as forensic markers of the severity of workplace safety failures.

The clinical presentation of silicosis is historically divided into three types, each representing a different failure in the hierarchy of industrial controls. Chronic (simple and complicated) silicosis is the most prevalent form, resulting from long-term exposure (over 10-20 years) to lower concentrations of RCS. In its simple form, it is characterized by small, discrete silicotic nodules (typically 2-5 mm) in the upper lung zones. If exposure continues, it may progress to complicated silicosis, or progressive massive fibrosis (PMF), where nodules coalesce into large masses of fibrous tissue. From a policy standpoint, chronic silicosis is the most under-reported, as symptoms often emerge only after a worker has left the hazardous workforce, complicating legal claims for compensation [11].

Accelerated silicosis manifests within 5-10 years of exposure to high dust concentrations. It has recently gained global notoriety due to its prevalence in the engineered stone (artificial quartz) industry, where silica content can exceed 90%. The rapid onset of this variant serves as a sentinel event, indicating that modern industrial processes are outstripping current regulatory safety limits [12].

The third variant, acute silicosis, occurring within weeks to months of massive exposure (*e.g.*, sandblasting in enclosed spaces without protection), is pathologically distinct. The alveoli fill with a lipid-rich, proteinaceous material, similar to pulmonary alveolar proteinosis. It is rapidly fatal and represents a total collapse of occupational health governance [13].

At the cellular level, silica particles engulfed by alveolar macrophages resist degradation and rupture the lysosomal membrane, triggering release of pro-inflammatory cytokines principally interleukin (IL)-1β *via* the NLRP3 inflammasome and tumor necrosis factor-α, which recruit fibroblasts to deposit collagen, forming the hallmark silicotic nodule [14-16]. Because silica is biologically inert and never cleared, this inflammatory cascade persists indefinitely, even after exposure ceases — the biological basis for the disease's irreversibility, and the reason why prevention, rather than treatment, remains the only rational public health response (Figure 1).

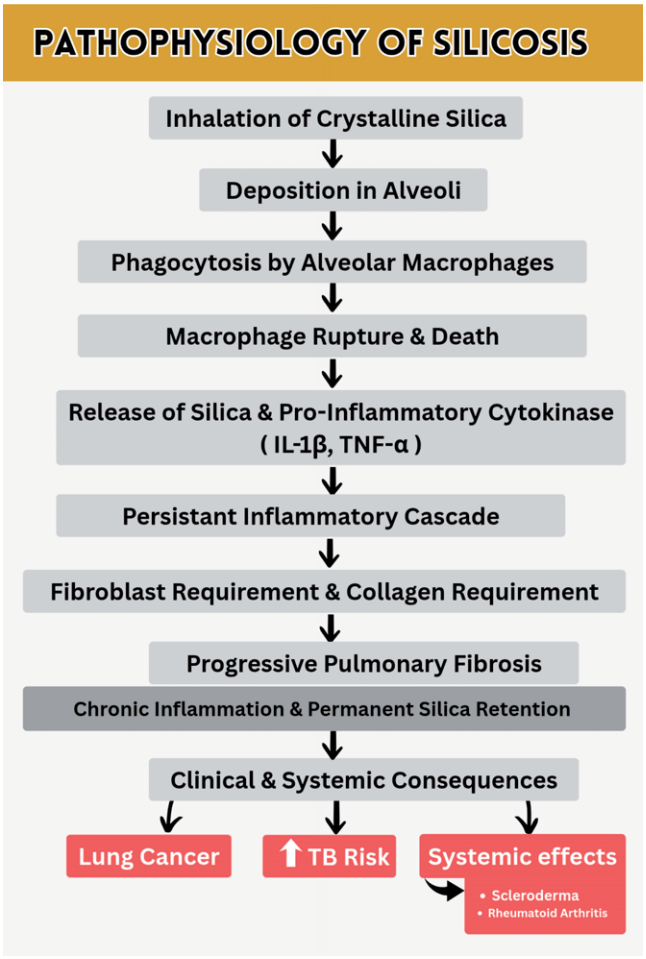


Figure 1. Schematic flowchart of silicosis pathophysiology.

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The public health impact of silicosis extends far beyond primary lung scarring, creating a syndemic effect with other infectious diseases. The most significant clinical complication in developing nations is the vastly increased risk of TB. Silica-laden macrophages are functionally impaired, losing their ability to inhibit the growth of *Mycobacterium tuberculosis*. Individuals with silicosis have a 3 to 30 times higher risk of developing TB compared to the general population [17]. This complicates policy, as occupational silicosis is frequently misdiagnosed, and thus only treated as pulmonary TB.

As PMF destroys the lung parenchyma, pulmonary vascular resistance increases, eventually leading to right-sided heart failure [18]. Chronic silica exposure is also linked to systemic conditions, including scleroderma, rheumatoid arthritis (Caplan's syndrome), and chronic kidney disease, highlighting that silicosis is a systemic industrial toxicity, not just a localized lung issue [19].

Epidemiology and burden: the global and national crisis

The epidemiological landscape of silicosis is characterized by a stark divide: while some high-income nations have seen a stabilization of cases, the global burden remains heavily concentrated in regions where industrial growth outpaces regulatory enforcement.

According to a comprehensive analysis of global burden of disease (GBD) data from 1990 to 2019, while the age-standardized incidence rate of silicosis has decreased globally (5383 per 100,000 population in 2019 as compared to 6.0-7.0 per 100,000 population in 1990), the absolute number of prevalent cases and deaths has continued to rise due to population growth and aging [20]. This study, covering 204 countries, highlights that the highest burdens remain in East Asia (110.240 per 100,000) and South Asia (12.389 per 100,000). Furthermore, the disability-adjusted life years (DALYs) (approximately 0.5 million) attributed to silicosis underscore its long-term impact on the global economy and healthcare systems, with predictions suggesting that without radical intervention, the burden will remain high through 2030 in rapidly industrializing regions.

The risk, however, is not uniform across all labor sectors. SSM, which employs approximately 49.5 million workers worldwide, in particular, has emerged as a focal point for a devastating silicosis-TB syndemic. In many developing countries, miners working in unregulated, artisanal sites are exposed to silica concentrations far exceeding permissible limits. This exposure leads to compromised alveolar macrophage function, making this population exponentially more susceptible to *Mycobacterium tuberculosis*. The overlap of these two diseases creates a double burden where the mortality rate is significantly higher than for either disease alone [21].

In India, the epidemiology of silicosis is inextricably linked to the informal economy, which employs over 90% of the at-risk population. Traditional sectors such as mining, slate-pencil manufacturing and agate polishing continue to report high clusters of disease. In Rajasthan and Gujarat, studies report localized silicosis prevalence ranging from 20% to 69%, with Jodhpur alone documenting 23,436 cases (12% prevalence) during mass screenings. High rates of silico-TB (up to 25%) further complicate the burden in quartz and agate sectors, yet comprehensive statewide incidence rates remain largely absent [6].

The update on the occupational burden of respiratory diseases emphasizes that the construction industry is now a leading source of silica exposure globally, including India, due to the widespread use of high-speed power tools for cutting concrete and stone without water suppression [22].

The persistence of silicosis in India is primarily a result of the invisibility of the workforce.

Workers in developing countries often move between rural homes and urban industrial sites. This circular migration means that by the time silicosis symptoms manifest, often years after the peak exposure, the worker is back in a rural setting where occupational history is rarely recorded by primary care physicians [23].

Because small-scale units often operate without formal registration, they bypass the scrutiny of the Directorate General of Mines Safety (DGMS). This lack of a formal employer-employee relationship prevents workers from accessing the Employees' State Insurance scheme, leaving them without medical or financial recourse.

Occupations associated with silica dust in India are estimated to have grown from 11.5 million workers in 2015-2016 to a projected 52 million by 2025-2026, exacerbating surveillance gaps. Amidst such rising numbers, under-reporting is another major challenge. Official statistics are frequently criticized for being conservative. The lack of standardized radiologic screening [International Labor Organization (ILO)-classified chest X-rays] at the primary healthcare level often incorrectly classifies occupational silicosis as treatment-resistant TB [7].

Determinants and risk factors: structural and biological drivers

The persistence of silicosis is driven by a synergistic combination of socioeconomic vulnerability, high-intensity exposure, and underlying biological predispositions. These factors function as a negative synergy for regulatory failure and physiological susceptibility.

The most significant determinant of silicosis remains the cumulative exposure dose. Systematic reviews of epidemiological evidence confirm a clear exposure-response relationship: higher concentrations of RCS significantly increase the risk of both silicosis and lung cancer [24].

Risk profiles vary sharply by sector. Longitudinal cohort studies comparing metal mines and pottery factories show that miners often face higher risks due to the sheer volume of dust and poor ventilation in enclosed shafts [25].

In sectors like Turkish ceramic manufacturing, the use of mechanized polishing and grinding without adequate dust suppression has been identified as a primary predictive risk factor for rapid disease development [26].

While engineering controls are paramount, the lack of effective personal protective equipment (PPE) remains a critical failure point, especially in artisanal settings. In field surveys of artisanal gold mining (*e.g.*, in Mongolia), it has been documented that workers often operate with no respiratory protection or use suboptimal substitutes like cloth wraps. This lack of PPE is compounded by dry processing methods, which elevate RCS levels far beyond permissible limits. Even when PPE is available, the lack of fit-testing and the prohibitive cost of replacing filters in low-income settings render these tools ineffective [27].

In addition, socioeconomic status often dictates the choice of high-risk labor. Poverty forces workers into unregulated informal

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sectors where they have little bargaining power for safety. Illiteracy prevents workers from comprehending the invisible nature of silica dust, leading to a lack of awareness regarding long-term health consequences.

Recent cohort studies have identified sex-related differences in risk. In some pottery industries, male workers have shown a significantly higher risk of silicosis compared to female counterparts, even after adjusting for exposure duration, suggesting that behavioral factors or physiological differences in lung deposition may play a role [28].

The persistence of the disease is fundamentally a result of the implementation gap in occupational health policy. In many jurisdictions, small-scale units bypass statutory inspections. This allows employers to operate with high dust levels and no medical surveillance, effectively externalizing the cost of the disease to the public health system.

Accountability latency is one of the major contributing factors. A retrospective cohort study in China highlighted that, as silicosis is a progressive disease, many workers continue to progress to end-stage fibrosis long after their employment has ended. This latency gap allows employers to evade legal and financial responsibility for the long-term health of their workforce [29].

Emerging research indicates that while exposure is the trigger, certain individuals are biologically more susceptible to the fibrotic process. Specific genetic variants and elevated levels of pro-inflammatory markers, specifically IL-18, IL-8, and CXCR2, have been linked to an increased risk of developing silicosis following exposure. These markers drive the frustrated phagocytosis cycle that leads to permanent scarring [30]. Multi-omics integration has identified novel genetic variants that predispose certain workers to higher fibrotic risks, suggesting that future policy might need to incorporate biological monitoring alongside environmental dust monitoring [31].

Silica exposure is also a significant risk factor for systemic autoimmune diseases, such as scleroderma and rheumatoid arthritis, indicating that the damage is not confined solely to the pulmonary system [32].

Prevention and control measures for silicosis

Engineering controls

Engineering controls are the most effective strategy for preventing silicosis because they reduce or eliminate silica exposure at the source, before reliance on personal protection. Numerous studies confirm that wet methods (*e.g.*, wet cutting, water sprays) and LEV significantly reduce RCS dust generation during high-risk tasks such as cutting, drilling, and grinding. A systematic literature review found that interventions aimed at dust control, including combined use of water misting, ventilation, and air currents, substantially reduced workplace dust concentrations, although residual exposure risk may persist if controls are suboptimal [33]. Engineering controls such as wet cutting and vacuum systems have been shown in construction settings to reduce worker exposures by >90%, highlighting their critical role in exposure reduction [34]. Moreover, early research demonstrated that control mechanisms like exhaust ventilation and wet methods are key to lowering silica dust generation during brick and concrete tasks, although they must be optimized and maintained to achieve target exposure reductions [35]. Engineered controls are also considered cost-effective compared with long-term healthcare costs and productivity losses, with economic analyses highlighting high health gains per investment in engineering interventions [36].

Despite this evidence, implementation remains inconsistent, particularly in informal sectors, due to cost barriers, lack of engineering expertise, and regulatory enforcement gaps. For instance, in India many small-scale factories fail to adopt exhaust systems or wet processing consistently, pointing to the need for policy and financing support [7].

Personal protective equipment

When engineering and administrative controls are insufficient to reduce exposures below safe levels, PPE such as respirators is essential. While the evidence base specifically quantifying PPE effectiveness against silicosis risk is mixed, systematic reviews assessing workplace dust control consistently note that respiratory protective equipment increases worker protection when used correctly alongside other controls. Studies of behavioral and training interventions have shown increased respirator use and improved attitudes toward PPE usage following targeted programs, indicating that worker education enhances effective PPE adoption [1].

However, PPE alone is considered the least preferred control in occupational hygiene because it depends upon consistent and correct use, proper fit testing, and maintenance, conditions that are often suboptimal, especially in small and informal worksites.

Medical surveillance

Medical surveillance is central to early detection of silicosis and other silica-related diseases, enabling protective actions before severe disease develops. Occupational health guidelines emphasize periodic medical examinations including chest imaging, spirometry, and clinical assessments for workers exposed above established criteria; this is mandated under many national standards (*e.g.*, the US Occupational Safety and Health Administration (OSHA) silica standard, which requires regular surveillance based on exposure level and duration). Evidence from reviews highlights that effective health surveillance helps identify early disease, track temporal trends, and support targeted interventions [8,37]. Despite these recommendations, many workplaces fall short in implementing systematic surveillance, leading to late diagnosis and continued exposure.

Workplace monitoring

Workplace monitoring of RCS concentrations through industrial hygiene sampling is necessary to ensure controls are effective and exposures remain below permissible limits. Regular air monitoring, combined with exposure assessment protocols, enables employers to evaluate the effectiveness of engineering and administrative controls, guide respirator selection, and comply with regulatory standards. Reviews advocate comprehensive exposure assessment programs with repeated sampling and documentation as a backbone of effective occupational silica control [1].

Compensation schemes and policy frameworks

Compensation and social protection systems provide financial support and care for workers already affected by silicosis. Published analyses show that improvements in compensation schemes enhance reporting and incentivize prevention by making employers more accountable. However, such schemes remain weak or poorly accessed in many countries. For example, in India, compensation provisions exist under laws like the Mines Act and Factories Act, but implementation challenges, including underreporting and lack of

worker awareness, limit their impact. Strengthening compensation schemes and linking them with active surveillance and disease notification can improve overall prevention efforts [38].

Guidelines and national policies

Several national and international guidelines endorse integrated preventive strategies combining engineering controls, PPE, surveillance, monitoring, and worker education. These include national occupational health standards in the US, UK, Australia, and emerging frameworks in other regions that mandate medical surveillance and exposure monitoring tied to specific silica exposure thresholds [1,7]. Also, global reviews recommend awareness campaigns and regulatory interventions, like those by Australian regulators for artificial stone work, which showed significant improvements in safe work practices following comprehensive training and enforcement programs [2].

Regulatory frameworks, policy gaps and the path to elimination

Despite longstanding recognition of silicosis as a preventable occupational disease, significant gaps in policy formulation, implementation, and enforcement continue to undermine efforts to reduce silica exposure globally. At the core of these gaps is weak regulatory enforcement, where exposure limits, even when legislated, are poorly monitored and often do not reflect the best available scientific evidence. For example, occupational exposure standards in many settings lag behind research recommendations, and routine air monitoring is infrequent or absent in informal and small-scale industries where silica exposure is highest. This regulatory deficiency allows hazardous exposure to persist, especially in mining and construction sectors that employ large numbers of vulnerable workers. Furthermore, the lack of coordinated surveillance data impedes the ability of health authorities to identify high-risk populations, track trends over time, and allocate resources effectively [6].

Another major policy gap is the lack of comprehensive surveillance and reporting systems. In many countries, especially low- and middle-income ones, silicosis cases remain underreported due to inadequate health information systems and limited integration of occupational disease notification into national health statistics. The absence of systematic medical surveillance protocols means that many cases go undiagnosed until late stages, limiting opportunities for early intervention and prevention of progression. At the policy level, there is often poor integration between occupational health frameworks and broader public health strategies**,** which weakens multi-sectoral action. For instance, silicosis control is rarely embedded within national noncommunicable disease programs or TB elimination efforts, despite evidence that silica exposure substantially increases TB risk [7]. This fragmentation results in missed opportunities for joint prevention, screening, and care pathways that could yield co-benefits for both diseases. To address these gaps, a series of targeted policy recommendations is needed.

A central but underappreciated dimension of this failure is the extraordinary heterogeneity of occupational exposure limits (OELs) for RCS across national jurisdictions, a disparity that means workers performing identical tasks face vastly different legal levels of protection depending solely on where they work. India's permissible exposure limit (PEL) of 0.15 mg/m^3 under the Metalliferous Mines Regulations, 1961, has remained unchanged for over six decades, and sits six-fold above the most protective international benchmark, the American Conference of Governmental Industrial Hygienists threshold limit value of 0.025 mg/m^3, and three-fold above the OSHA standard of 0.05 mg/m^3 [33,34]. Field studies of Indian sandstone mine workers have documented silicosis occurring even at concentrations below this legal limit, establishing that the current standard is not merely outdated but scientifically demonstrably insufficient to protect worker health [39].

The disparity in OELs is not merely a technical matter of numbers; it represents fundamentally different political choices about whose health is worth protecting. The United States OSHA 2016 silica rule exemplifies a comprehensive, multi-obligation approach. Employers must maintain exposure below the PEL, conduct air monitoring, maintain a written exposure control plan, provide medical surveillance including chest radiography and spirometry at defined intervals, train workers, and retain records for 30 years [40]. In 2024, the Mine Safety and Health Administration (MSHA) harmonized the previously outdated mining standard to the same 0.05 mg/m^3 PEL, and additionally mandated reporting of measured overexposures directly to MSHA – a stronger early-warning function absent from the original OSHA rule [41]. Australia represents perhaps the most progressive regulatory evolution globally. Beyond OEL compliance, its 2025 Model Code of Practice requires employers to reduce RCS exposure as low as reasonably practicable, not merely below the legal limit [42]. More significantly, in July 2024, Australia became the first country in the world to impose a complete national prohibition on the manufacture, supply, and installation of engineered stone, made in direct response to an epidemic of accelerated silicosis among stonemasons [43]. This reflects the highest rung of the hierarchy of controls, hazard elimination rather than limit management.

India's regulatory architecture, by contrast, is characterized by jurisdictional fragmentation. The DGMS exercises authority exclusively over registered mines, while factory inspectorates cover registered factories. Agate polishing units in Khambhat, slate pencil units in Mandsaur, stone crushing operations in Rajasthan, and construction sites, the very loci of highest disease burden, frequently operate as unregistered micro-enterprises that fall outside the inspection mandate of any single authority [5,6]. The result is an enforcement vacuum in which the populations most at risk are precisely those that regulatory agencies have the least operational capacity to reach. The Occupational Safety, Health and Working Conditions Code (OSH Code), 2020, enacted to consolidate 13 central labor laws, had not been fully operationalized across all states at the time of writing, leaving the fragmented legacy framework intact [6].

A particularly consequential policy gap is the failure to embed silicosis control within national TB elimination programs, despite robust epidemiological evidence that silica-exposed individuals face a 3 to 30-fold increased risk of active TB [17]. In the Indian context, a substantial proportion of TB cases presenting at primary health centers in mining districts represent silico-TB misclassified as drug-resistant pulmonary TB, resulting in inappropriate treatment regimens and missed opportunities for both occupational compensation and workplace intervention [6]. A structured expert consensus framework for implementing collaborative TB-silicosis activities in India has been published, proposing a bidirectional screening model: all patients diagnosed with silicosis should be screened for active TB, and all silica-exposed workers should be assessed for latent TB infection [7]. The framework recommends standardized ILO-classified chest radiography as the shared diagnostic platform for both disease pathways, the establishment of

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referral pathways between occupational health and TB care services, and workplace-based preventive interventions. It calls explicitly for coordinated action across the Ministries of Health, Labor, Industry, and Environment, a governance architecture that India does not yet have in place. Integrating this bidirectional model within the National TB Elimination Program's district-level framework, and mandating occupational history as a compulsory field in all TB notification forms, would represent a high-yield, low-cost reform that simultaneously advances both agendas.

Drawing from the previously reported studies, the following priority regulatory reforms are proposed.

i. Immediate revision of India's RCS PEL: reduce the PEL from 0.15 mg/m³ to 0.05 mg/m³, aligning with the OSHA standard, with an action level of 0.025 mg/m³ triggering enhanced monitoring and medical surveillance. Given documented disease occurrence below the current PEL, this revision is a scientific imperative, not merely a policy preference [34,39].
ii. Full operationalization of the OSH Code 2020: prioritize notification of all provisions related to dust monitoring, medical surveillance, and occupational disease notification. Establish penalties proportionate to harm severity and build state-level inspection capacity in high-risk districts [6].
iii. Extend regulatory coverage to the informal sector: mandate registration of all dust-generating establishments regardless of workforce size. Introduce supply-chain liability provisions requiring principal employers, construction contractors, and quarry operators to ensure compliance across their contracted workforce [6,21].
iv. Implement the TB-silicosis bidirectional screening framework: adopt the published expert consensus framework [7] as a pilot program in high-prevalence districts, with a defined roadmap for national scale-up. Mandate occupational history as a compulsory field in all TB notification forms under the National Tuberculosis Elimination Program.
v. Apply the precautionary principle to emerging high-silica industries: issue product-specific regulatory instruments for engineered stone fabrication and ramming mass production, including mandatory wet-working protocols and LEV requirements. Commission a regulatory impact assessment of an engineered stone prohibition, modelled on the Australian precedent, given documented outbreaks of accelerated silicosis in Indian workers [8,13].

These five reforms reflect a paradigm shift from silicosis management toward silicosis elimination, one that demands regulatory courage, inter-ministerial coordination, and a fundamental reorientation of occupational health governance toward covering all workers, not merely those in the formal sector. The international evidence is unambiguous: where strict limits are actively enforced, disease incidence falls. Where legal standards exist without funded enforcement, silicosis persists. India has the legislative architecture, the scientific evidence, and the international commitments to act. What remains is the political will to translate them into practice.

Ethical, social and economic implications of silicosis

Silicosis is not just a preventable occupational disease; it also embodies profound ethical, social, and economic injustices that disproportionately affect vulnerable worker populations. Globally, the disease continues to cause significant morbidity and mortality, with a rising number of incident cases, deaths, and DALYs attributed to occupational silica exposure, particularly in low- and middle-income countries where regulatory enforcement and health systems are weak. The GBD study 2021 estimates that although age-standardized rates of silicosis have declined in some regions, the absolute number of cases and silicosis-related deaths remains high, exerting substantial societal cost across generations [44].

Preventable deaths and ethical concerns

A key ethical concern is that silicosis deaths are largely preventable with well-known control measures, yet they persist due to failures in policy and industry accountability. Observational epidemiology demonstrates a strong dose-response relationship between silica exposure and increased mortality, underlining that continued exposure directly translates into preventable deaths. This dose-response relationship reinforces that policy failings, rather than biological inevitability, are responsible for many silicosis fatalities [45].

The ethical obligation to prevent clear health harms is echoed in occupational health literature, which frames silica exposure as unjust because workers often lack informed consent or adequate protection. This disproportionate health risk among workers with limited agency raises serious moral questions about employer responsibilities and the ethics of placing profit over human life [7].

Economic burden on families and communities

Silicosis imposes severe economic burdens on affected families and communities. As an irreversible chronic disease, silicosis leads to reduced earning capacity, long-term healthcare needs, and often premature loss of the primary breadwinner. A public health review from India argues that the economic costs of morbidity and mortality from silicosis, including lost productivity, medical expenses, and diminished workforce participation, are considerable and yet receive insufficient policy attention. Workers in the unorganized sector often must rely on state dole or inadequate compensation schemes, which frequently fail to offset the true financial impact on households [46].

Internationally, research on other occupational lung diseases (*e.g.*, pneumoconiosis including silicosis) shows that chronic respiratory disability is associated with direct economic costs such as medical care and lost wages, and indirect costs like reduced employment opportunities and decreased quality of life. These economic burdens disproportionately affect low-income households, leading to poverty traps that extend beyond the initial worker to entire families [47].

Human rights perspectives

From a human rights perspective, silicosis prevention and relief have increasingly been linked to fundamental rights such as the right to life, health, and dignified work. Legal analyses document how failure to enforce silicosis prevention measures violates constitutional rights to health and dignity, and how judicial interventions have pushed governments toward obligatory obligations rather than voluntary standards in occupational health. In India, recent high-court rulings have framed the state's duty to prevent silicosis as a constitutional obligation, marking a significant shift from conventional policy to a rights-based accountability model**.** Such decisions strengthen the normative foundation for occupational health protections and highlight that prevention of occupational diseases like silicosis is not only a public health imperative but also a legal and ethical obligation grounded in human rights frameworks [48].

Conclusions

Silicosis is a profound ethical and public health failure, persisting not due to a lack of medical knowledge, but as a direct result of regulatory and systemic inadequacies. The shift from legacy mining to modern high-silica industries has outpaced current safety frameworks, leaving millions of vulnerable workers without adequate protection or legal recourse. Addressing this "preventable yet persistent" epidemic necessitates a multi-sectoral approach that prioritizes the hierarchy of engineering controls such as mandatory wet-working and exhaust ventilation, over less reliable personal protection. Healthcare professionals must act as the primary line of defense through vigilant early screening and the meticulous documentation of occupational histories to prevent misdiagnosis. Furthermore, classifying silicosis as a mandatory notifiable disease and establishing unified surveillance platforms across health and labor ministries are essential steps to ensure the invisibility of the workforce is finally countered. By framing silicosis prevention as a fundamental human right and a constitutional obligation, the public health system can move from passive management toward the total elimination of this irreversible occupational hazard.

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Received: 10 February 2026; Accepted: 2 June 2026; Early view: 3 July 2026.

Contributions: Pradnya Rajmane: study concept and design, critical revisions, and approval of the final version. Mandati Santhosh Reddy, Rametrika Saha, Revanasiddappa Devariniti: data collection, writing of the first draft of the manuscript. Rametrika Saha, Ayushi Devagekar: figure. All the authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of interest: the authors declare that they have no competing interest, and all authors confirm accuracy.

Ethics approval and consent to participate: not applicable.

Informed consent: not applicable.

Patient consent for publication: not applicable.

Availability of data and materials: derived data supporting the findings of this study are available from the corresponding author on request.

Acknowledgments: the authors express their gratitude to the Principal and all the faculty members of the Department of Pharmacy Practice, KLE College of Pharmacy, Belagavi.

Declaration of generative artificial intelligence and artificial intelligence-assisted technologies in the writing process: the authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were used in the writing process of this manuscript.

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