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Review Article

A Conceptual Framework of Biological Effects of Environmental Contaminants and Health Risks among Street Cleaners and Road Workers

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Abstract: Urban transportation systems are major sources of environmental contamination, generating complex mixtures of airborne particles, heavy metals, and organic pollutants that accumulate along roadways and in surrounding areas. These pollutants originate primarily from vehicular emissions, mechanical wear of vehicle components, and atmospheric deposition associated with urban industrial activities. Occupational groups working directly in these environments may therefore experience greater exposure to environmental contaminants than the general population. The purpose of this paper is to develop a theoretical model of the biological effects of environmental contaminants and health risks in street cleaners and road workers based on a detailed review of the existing literature**.** The results for occupational health outcomes show that exposure to particulate matter generated by sweeping and waste collection is an important determinant of respiratory risk among sanitation workers. Environmental monitoring studies have demonstrated elevated airborne particulate concentrations during manual sweeping operations, particularly under dry conditions when accumulated road dust is easily re-suspended into the breathing zone of workers. Furthermore, repeated exposure to these airborne particles may therefore contribute to chronic respiratory irritation and the development of respiratory disorders among street cleaners. Cardiopulmonary health effects have also been reported in association with exposure to particulate air pollution, while epidemiological and toxicological studies have demonstrated that inhalation of fine and ultrafine particulate matter can trigger systemic inflammatory responses and oxidative stress that extend beyond the respiratory tract. These biological responses may contribute to alterations in vascular function, increased blood pressure, and disturbances in autonomic regulation of the cardiovascular system. Street cleaners and road maintenance workers experience repeated occupational exposure to particulate matter and traffic emissions in roadway environments, conditions that may increase vulnerability to cardiopulmonary effects associated with urban air pollution. The paper concludes that the existing literature demonstrates that roadway environments contain multiple environmental contaminants capable of producing adverse biological effects. However, important knowledge gaps remain regarding the magnitude of exposure among street cleaners and road maintenance workers, the biological mechanisms linking these exposures to disease outcomes, and the effectiveness of strategies to mitigate occupational health risks. Finally, by addressing these gaps through integrated environmental monitoring, biomonitoring, and longitudinal epidemiological research will be essential for advancing understanding of the biological effects of environmental contaminants in this occupational population.
Keywords: Biological Effects, Work and Road Environment, Environmental, Contaminants, Health Risks, Street Cleaners, Road Workers.

INTRODUCTION

Urban transportation systems represent major sources of environmental contamination, generating complex mixtures of airborne particles, heavy metals, and organic pollutants that accumulate along roadways and surrounding environments. These pollutants originate primarily from vehicular emissions, mechanical wear of vehicle components, and atmospheric deposition associated with urban industrial activities. Numerous environmental monitoring studies have demonstrated that traffic corridors serve as hotspots for particulate matter (PM), heavy metals, polycyclic aromatic hydrocarbons (PAHs), and other toxic contaminants that accumulate in road dust and roadside soils (Amato *et al.*, 2014; Wei & Yang, 2010). Occupational groups working directly in these

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environments may therefore experience greater exposure to environmental contaminants than the general population.

Among these occupational populations, street cleaners and highway maintenance workers represent a particularly vulnerable workforce because their daily activities involve direct interaction with contaminated road surfaces and traffic-generated pollutants. Street cleaning and road maintenance tasks such as sweeping, waste collection, pavement repair, and asphalt paving disturb accumulated road dust and resuspend particulate matter into the breathing zone of workers. As a result, these workers are exposed to airborne pollutants originating from vehicular emissions, brake wear, tire abrasion, and mechanical degradation of road materials (Grigoratos & Martini, 2015; Amato *et al*., 2014). Studies examining the chemical composition of road dust consistently demonstrate that urban road sediments contain elevated concentrations of toxic metals, including lead, cadmium, chromium, nickel, copper, and zinc, reflecting long-term deposition of traffic-related pollutants (Wei & Yang, 2010; Lu *et al*., 2009).

Street cleaning operations represent an important pathway through which accumulated road contaminants become airborne. During sweeping activities, dust deposited on road surfaces is resuspended into the atmosphere, increasing inhalation exposure to particulate matter and associated toxic compounds. Research on occupational exposure among street sweepers has shown that these workers experience significantly higher concentrations of airborne dust than control populations (Ghosh *et al*., 2014). Similarly, studies examining respiratory health among street cleaners have reported increased prevalence of chronic cough, wheezing, and reduced lung function among workers exposed to road dust and traffic-related air pollution (Njeru, 2024). These findings suggest that repeated exposure to contaminated dust may contribute to respiratory morbidity among sanitation workers.

Highway maintenance and road construction workers experience similar exposure environments but are also exposed to additional contaminants associated with road repair and paving activities. Asphalt paving, cutting, grinding, and drilling of pavement materials release a variety of chemical pollutants, including volatile organic compounds, PAHs, and respirable crystalline silica particles. Asphalt fumes generated during hot-mix paving operations have been shown to contain PAHs and other organic compounds that can cause respiratory irritation and potential long-term health effects (Cui *et al*., 2020). In addition, diesel-powered construction equipment and passing traffic contribute to elevated concentrations of diesel exhaust particles within roadway work zones. Diesel exhaust has been classified as carcinogenic to humans based on evidence linking occupational exposure to increased lung cancer risk (IARC, 2012).

Particulate matter generated in traffic environments represents one of the most significant environmental exposures affecting roadway workers. Traffic-related particles originate not only from combustion emissions but also from non-exhaust sources such as brake wear, tire abrasion, and road surface erosion (Amato *et al*., 2014; Grigoratos & Martini, 2015; Thorpe & Harrison, 2008). Non-exhaust emissions have become increasingly important contributors to urban particulate matter concentrations as vehicle emission standards have reduced exhaust emissions (Grigoratos & Martini, 2015). These particles often contain high concentrations of transition metals and organic compounds that increase their oxidative potential and biological toxicity (Kelly & Fussell, 2012). Because street cleaners and road workers operate near traffic emissions and frequently disturb deposited dust, they may experience elevated exposure to both exhaust and non-exhaust particulate pollutants.

Heavy metal contamination represents another important environmental exposure pathway for roadway workers. Road dust and roadside soils frequently accumulate metals derived from vehicular traffic and industrial emissions. Geochemical studies examining roadside environments have reported elevated concentrations of lead, cadmium, chromium, nickel, copper, and zinc in urban dust samples, reflecting long-term deposition of traffic-related pollutants (Wei & Yang, 2010; Lu *et al*., 2009). These metals originate from multiple vehicular sources, including brake linings, tire wear particles, fuel combustion residues, and lubricating oil emissions (Grigoratos & Martini, 2015; Amato *et al*., 2014). Once deposited on road surfaces, these contaminants become incorporated into fine particulate fractions that can be resuspended during sweeping and road maintenance activities, increasing inhalation exposure among street cleaners and highway workers (Amato *et al*., 2014; Thorpe & Harrison, 2008; Wei & Yang, 2010).

Organic pollutants, such as polycyclic aromatic hydrocarbons, also contribute to the contaminant mixture in roadway environments. Polycyclic aromatic hydrocarbons are generated primarily from the incomplete combustion of fossil fuels and are commonly detected in vehicle exhaust and asphalt fumes (Kim *et al*., 2013). Asphalt paving operations expose workers to polycyclic aromatic hydrocarbons and volatile organic compounds that are released when heated bitumen is applied to road surfaces (Cui *et al*., 2020). Biomonitoring studies frequently use urinary 1-hydroxypyrene as an indicator of polycyclic aromatic hydrocarbon exposure among occupational populations exposed to combustion-related pollutants (Jongeneelen, 2001).

In addition to chemical contaminants, roadway workers may encounter biological pollutants associated with waste handling and environmental debris. Street cleaning activities frequently involve contact with decomposing organic materials, which can release microbial aerosols and endotoxins into the surrounding air. Environmental monitoring studies have reported the presence of airborne bacteria and fungal spores in waste collection and street sanitation environments, suggesting that sanitation workers may experience bioaerosol exposure capable of inducing respiratory irritation and inflammatory responses (Bleck & Wettberg, 2012).

The biological effects associated with exposure to these environmental contaminants involve several interconnected mechanisms. One of the most widely studied mechanisms is oxidative stress, which occurs when reactive oxygen species generated by pollutants overwhelm the body's antioxidant defense systems (Kelly & Fussell, 2012; Jaishankar *et al*., 2014; Jomova & Valko, 2011). Fine particulate matter and metal-containing particles can catalyze the formation of reactive oxygen species in lung tissue, leading to lipid peroxidation, DNA damage, and disruption of cellular signaling pathways (Kelly & Fussell, 2012). Persistent oxidative stress may trigger inflammatory responses that contribute to chronic respiratory disease and cardiovascular dysfunction (Brook *et al*., 2010; Cassee *et al*., 2013; Kelly & Fussell, 2012).

Genotoxic effects represent an additional concern associated with exposure to environmental contaminants in roadway environments. Several pollutants commonly detected in traffic-related air pollution, including PAHs and certain heavy metals, can interact with DNA and induce mutations (Boström *et al*., 2002; Jaishankar *et al*., 2014; Kim *et al*., 2013; Valko *et al*., 2005). PAHs can form DNA adducts following metabolic activation, while oxidative stress generated by metal-containing particles can cause DNA strand breaks and chromosomal abnormalities (Boström *et al*., 2002; Jaishankar *et al*., 2014; Jomova & Valko, 2011; Kim *et al*., 2013; Valko *et al*., 2005). These mechanisms provide a biological basis for the increased cancer risk associated with long-term exposure to traffic-related air pollution (Boström *et al.,* 2002; IARC, 2012; Kim *et al*., 2013).

Despite the growing body of research examining environmental pollution and health outcomes, relatively few studies have comprehensively examined the combined exposure experienced by street cleaners and road maintenance workers. Most investigations have focused on individual pollutants or specific occupational tasks rather than evaluating the cumulative impact of multiple environmental contaminants (Cassee *et al*., 2013; Kelly & Fussell, 2012). However, these workers are simultaneously exposed to particulate matter, heavy metals, diesel exhaust, PAHs, silica dust, and biological contaminants. The interaction of these exposures may produce cumulative or synergistic biological effects that are not fully captured by studies focusing on single pollutants.

Purpose of the Paper:

The purpose of this paper is to develop a theoretical model of the biological effects of environmental contaminants and health risks in street cleaners and road workers based on a detailed review of the existing literature.

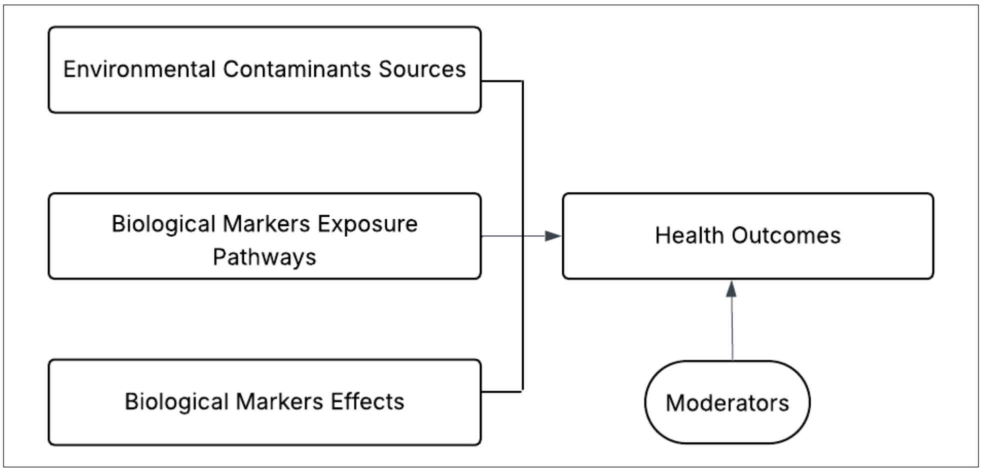

Figure 1: Conceptual Framework

Analysis of Framework

This section discusses the four factors of the conceptual framework, Figure 1 above, for biological effects of environmental contaminants and health risks in street cleaners and road workers in detail. It analyses the relevance of these factors by drawing on existing research work.

Environmental Contaminants in Roadway Occupational Environments sources

Road Dust and Heavy Metal Contamination

The environmental chemistry of road dust consistently demonstrates that vehicular traffic represents a dominant source of urban sediment contamination (Amato *et al*., 2014; Thorpe & Harrison, 2008; Wei & Yang, 2010). Brake wear has been identified as a major contributor of copper, antimony, and iron particles, while tire abrasion produces particles enriched in zinc and other metals used in tire manufacturing (Grigoratos & Martini, 2015). Combustion emissions from gasoline and diesel engines also release fine particulate matter containing metals and organic compounds that can deposit onto roadway surfaces (Amato *et al*., 2014). In addition to direct vehicular emissions, atmospheric deposition from industrial sources and long-range transport of pollutants contribute to contaminant accumulation in roadside sediments (Wei & Yang, 2010).

Numerous environmental monitoring studies have documented elevated concentrations of heavy metals in urban road dust. Investigations of roadside soils and street dust have reported significant enrichment of metals, including lead, cadmium, chromium, copper, nickel, and zinc, above background environmental levels (Lu *et al*., 2009; Wei & Yang, 2010). Similar findings have been reported in geochemical studies examining road dust contamination in densely populated urban areas (Mostafa *et al*., 2024; Lu *et al*., 2009). For example, analyses of urban road dust in Cairo demonstrated substantial accumulation of heavy metals derived from traffic emissions and urban industrial activities, with concentrations exceeding natural background levels for several toxic elements (Mostafa *et al*., 2024). These findings support the conclusion that urban road dust reflects the cumulative deposition of pollutants generated by transportation systems and surrounding anthropogenic activities.

Road dust contamination is also influenced by mechanical stress generated by vehicle movement. Repeated friction between tires and road surfaces contributes to the release of metal-containing particles that accumulate on roadway sediments (Singh *et al*., 2018; Grigoratos & Martini, 2015; Thorpe & Harrison, 2008). Research examining vehicular stress-related contamination has shown that mechanical abrasion processes can significantly increase the concentration of metals such as copper, zinc, and iron in road dust samples collected from heavily trafficked roadways (Singh *et al*., 2018). These processes highlight the complex interactions between traffic activity, mechanical wear, and environmental contamination in urban transportation systems.

For street cleaners and road maintenance workers, the accumulation of contaminants in road dust represents a major occupational exposure pathway. Street cleaning activities frequently disturb deposited sediments, re-suspending fine particulate matter into the breathing zone of workers (Amato *et al*., 2014; Thorpe & Harrison, 2008; Wei & Yang, 2010). Environmental monitoring studies have shown that sweeping operations can significantly increase airborne dust concentrations relative to background ambient levels (Amato *et al*., 2014). Workers performing manual sweeping are therefore exposed to re-suspended particles containing metals, organic compounds, and other pollutants that were originally deposited by traffic emissions.

The health significance of road dust exposure is strongly influenced by particle size distribution and chemical composition. These particles can remain suspended in the air for extended periods and penetrate deeply into the respiratory tract upon inhalation. Occupational exposure to fine metal-containing particles may therefore contribute to respiratory and systemic health risks among workers who routinely operate within contaminated roadway environments.

Biological Makers Exposure Pathways

Traffic Related Particulate Matter (PM)

Traffic-related particulate matter is among the most significant environmental contaminants affecting occupational populations working in roadway environments. Vehicular activity generates particulate matter through both exhaust emissions and non-exhaust processes such as brake wear, tire abrasion, and road surface degradation (Amato *et al*., 2014; Thorpe & Harrison, 2008). These particles accumulate along transportation corridors and contribute substantially to urban air pollution levels (Kelly & Fussell, 2012). Because street cleaners and highway maintenance workers perform their duties directly in these environments, they may experience greater exposure to particulate matter than the general population.

Vehicular exhaust emissions represent a major source of fine and ultrafine particulate matter in urban environments. Combustion of gasoline and diesel fuels produces particles composed primarily of elemental carbon cores coated with organic compounds, trace metals, and sulfates formed during fuel combustion (Kittelson, 1998; Kelly & Fussell, 2012). Diesel engines generate large numbers of ultrafine particles coated with organic compounds, such as polycyclic aromatic hydrocarbons, and trace metals originating from fuel combustion and engine wear (Kittelson, 1998; IARC, 2012). Therefore, due to their extremely small size and large surface area, diesel exhaust particles can penetrate deeply into the respiratory tract following inhalation and may contribute to respiratory and cardiovascular health effects (Brook *et al*., 2010).

In addition to exhaust emissions, non-exhaust traffic sources have been increasingly recognized as important contributors to urban particulate pollution. Mechanical wear processes occurring during vehicle operation generate substantial quantities of particulate matter that accumulate on road surfaces (Amato *et al*., 2014; Thorpe & Harrison, 2008; Grigoratos & Martini, 2015). Brake wear particles contain metals such as copper, iron, and antimony derived from brake pad materials, while tire wear particles contain zinc and other metals used during tire manufacturing (Grigoratos & Martini, 2015). Several environmental monitoring studies have demonstrated that non-exhaust emissions can represent a substantial proportion of total traffic-related particulate matter in urban areas, particularly in regions where vehicle emission standards have reduced exhaust emissions (Amato *et al*., 2014).

Occupational exposure studies conducted among roadway workers have documented elevated concentrations of particulate matter during street cleaning, waste collection, and road maintenance activities (Ghosh *et al*., 2014; Njeru, 2024; Sabde & Zodpey, 2008). Environmental monitoring investigations have shown that sweeping operations can significantly increase airborne particulate concentrations by resuspending deposited road dust into the breathing zone of workers (Amato *et al*., 2014). Similarly, occupational health studies examining street sweepers have reported increased exposure to respirable dust and traffic-related particulate matter compared with non-exposed populations, particularly during manual sweeping operations conducted under dry environmental conditions (Ghosh *et al*., 2014; Njeru, 2024).

The chemical composition of traffic-related particulate matter plays a critical role in determining its biological toxicity. Research examining particulate matter beyond mass concentration has demonstrated that particle composition, emission source, and oxidative potential are important determinants of health effects associated with particulate exposure (Kelly & Fussell, 2012). Traffic-derived particles frequently contain transition metals and organic compounds that can generate reactive oxygen species upon deposition in lung tissue (Kelly & Fussell, 2012). These oxidative processes have been linked to inflammatory responses and cellular damage observed in populations exposed to particulate air pollution (Brook *et al*., 2010).

Exposure to particulate matter generated by traffic sources has been associated with numerous adverse health outcomes. Epidemiological studies have demonstrated that exposure to particulate air pollution is associated with increased risk of respiratory disease, cardiovascular morbidity, and premature mortality (Brook *et al*., 2010). Because street cleaners and road maintenance workers repeatedly encounter traffic-generated particles during routine occupational activities, they may represent a population at elevated risk for pollution-related health effects.

Polycyclic Aromatic Hydrocarbons and Asphalt Emissions

Polycyclic aromatic hydrocarbons represent an important class of organic pollutants commonly detected in urban transportation environments. These compounds are primarily generated by incomplete combustion of fossil fuels and are widely emitted from vehicle exhaust, industrial processes, and asphalt-related activities (Kim *et al*., 2013). Roadway environments tend to concentrate both traffic emissions and the asphalt materials used in pavement construction, leading to frequent detection of polycyclic aromatic hydrocarbons in roadside air, accumulated road dust, and urban surface sediments near transportation corridors (Ravindra *et al*., 2008). Therefore, occupational populations working within these environments may experience elevated exposure to these compounds.

Vehicle exhaust emissions are among the major sources of polycyclic aromatic hydrocarbons in urban environments. Combustion of gasoline and diesel fuels produces a mixture of low- and high-molecular-weight polycyclic aromatic hydrocarbons that are emitted into the atmosphere, attached to fine particulate matter (Kim *et al*., 2013). Once emitted, these compounds may remain suspended in the atmosphere or become deposited onto road surfaces where they accumulate in environmental sediments and road dust (Ravindra *et al*., 2008).

In addition to inhalation exposure, dermal contact with asphalt materials may contribute to internal absorption of polycyclic aromatic hydrocarbons during paving operations. Occupational exposure studies examining asphalt workers have demonstrated that skin exposure to asphalt fumes and contaminated materials can represent an important pathway of polycyclic aromatic hydrocarbon uptake, particularly when workers handle heated asphalt mixtures without adequate protective equipment (Burstyn *et al*., 2002; Kim *et al*., 2013). Both inhalation and dermal exposure routes, therefore, contribute to workers' internal dose of polycyclic aromatic hydrocarbons engaged in road construction and asphalt paving activities.

The toxicological significance of polycyclic aromatic hydrocarbons lies in their ability to undergo metabolic activation in the human body. Many polycyclic aromatic hydrocarbons are considered procarcinogen compounds that require enzymatic activation before interacting with cellular macromolecules (Boström *et al*., 2002; Kim *et al*., 2013; Ravindra *et al*., 2008). During metabolic activation, these compounds can form reactive intermediates that bind to DNA, forming DNA adducts that interfere with normal cellular replication (Kim *et al*., 2013). Formation of DNA adducts and other genotoxic alterations has been widely recognized as a key mechanism linking exposure to polycyclic aromatic hydrocarbons with increased cancer risk in occupational and environmental settings (Boström *et al*., 2002; Kim *et al*., 2013).

Diesel Exhaust Exposure

Diesel exhaust represents another significant source of traffic-related air pollution in transportation environments. Diesel-powered engines are widely used in trucks, buses, and heavy equipment, which commonly operate along roadways and construction sites, resulting in substantial emissions of particulate matter and gaseous pollutants (IARC, 2012; Kittelson, 1998; Pronk *et al*., 2009). Diesel exhaust is a complex mixture composed of particulate matter, nitrogen oxides, carbon monoxide, volatile organic compounds, and trace metals produced during fuel combustion (Kittelson, 1998; IARC, 2012). Street cleaners and road maintenance personnel work near traffic and diesel-powered machinery, increasing their risk of exposure to diesel exhaust. Diesel engines generate large numbers of ultrafine particles that contribute significantly to traffic-related particulate pollution. These particles consist primarily of elemental carbon cores coated with organic compounds, including polycyclic aromatic hydrocarbons and other combustion products derived from fuel and lubricating oil (Kittelson, 1998; Kelly & Fussell, 2012). Trace metals originating from engine wear and fuel impurities may also be incorporated into diesel particulate emissions (Kelly & Fussell, 2012). Due to their extremely small size and high surface area, diesel exhaust particles can adsorb toxic organic compounds and metals, thereby increasing their biological reactivity following inhalation.

The small size of diesel particulate matter allows these particles to penetrate deeply into the respiratory tract. Ultrafine particles emitted from diesel engines can reach the alveolar region of the lungs and may translocate across the alveolar barrier into the systemic circulation (Brook *et al*., 2010). This ability to enter the bloodstream has raised concerns regarding the potential for diesel exhaust particles to contribute to both respiratory and cardiovascular health effects. Epidemiological studies have demonstrated associations between exposure to diesel exhaust and increased risk of respiratory symptoms, lung function impairment, and cardiovascular disease (Brook *et al*., 2010).

Occupational exposure to diesel exhaust has been investigated in numerous workplace environments, particularly among workers involved in transportation, construction, and road maintenance activities (IARC, 2012; Pronk *et al*., 2009; van Tongeren *et al*., 2002). Measurements conducted in occupational settings have shown that workers operating near diesel-powered equipment may experience elevated concentrations of diesel particulate matter compared with ambient urban levels (Pronk *et al*., 2009). In roadway work zones, the presence of heavy equipment, passing vehicles, and confined work areas may contribute to the accumulation of diesel exhaust particles in workers' breathing zones.

Evidence from occupational epidemiology has also linked long-term exposure to diesel exhaust with increased cancer risk. Based on sufficient evidence from human epidemiological studies and experimental research, the International Agency for Research on Cancer classified diesel engine exhaust as carcinogenic to humans (Group 1) (IARC, 2012). This classification was based primarily on evidence demonstrating increased lung cancer risk among workers exposed to diesel exhaust in occupations such as mining, trucking, and heavy equipment operation (IARC, 2012). These findings highlight the potential health risks of chronic exposure to diesel emissions in occupational settings.

Street cleaners and road maintenance workers experience repeated occupational exposure to diesel exhaust in roadway environments through routine work near traffic and diesel-powered machinery. Workers performing road repairs, sweeping operations, and waste collection tasks frequently operate near vehicles that emit diesel exhaust particles (IARC, 2012; Pronk *et al*., 2009; Nieuwenhuijsen, 2015). Given that these exposures can occur repeatedly over long periods, diesel exhaust exposure has become a significant occupational health concern for workers involved in roadway maintenance and sanitation services.

Understanding the contribution of diesel exhaust to occupational exposure in transportation environments is therefore essential for evaluating the cumulative health risks faced by street cleaners and highway maintenance workers. Diesel emissions represent one component of a broader mixture of environmental contaminants present in roadway environments, and their interaction with other pollutants may influence the biological effects associated with occupational exposure.

Crystalline Silica Exposure in Roadway Work Environments

Monitoring studies conducted in occupational environments have demonstrated that mechanical processing of construction materials can generate substantial concentrations of respirable crystalline silica in workplace air (Flanagan *et al*., 2006; Linch, 2002). Activities such as pavement cutting, drilling, grinding, and surface repair can release fine silica particles derived from construction materials, including crushed stone aggregates and cement-based pavement mixtures. Similar observations have been reported in studies examining roadway construction and maintenance environments, where dust generated during pavement repair operations contains significant fractions of crystalline silica originating from mineral aggregates used in asphalt and concrete pavement (Flanagan *et al.,* 2006; Linch, 2002).

Road dust itself can also represent an important source of crystalline silica exposure. Mineral particles present in roadway sediments originate partly from the degradation of pavement materials and partly from the erosion of construction aggregates used in road infrastructure (Thorpe & Harrison, 2008). Traffic movement, wind turbulence, and mechanical sweeping operations may resuspend these mineral particles into the atmosphere, increasing the potential for inhalation exposure among street cleaners and sanitation workers (Amato *et al*., 2014; Thorpe & Harrison, 2008). Environmental monitoring investigations have demonstrated that resuspended road dust frequently contains mineral components, such as quartz and other silica-containing particles, derived from pavement materials and surrounding soils (Thorpe & Harrison, 2008).

The toxicological consequences of exposure to respirable crystalline silica have been extensively documented in occupational health research (Leung *et al*., 2012; Linch, 2002). Inhalation of silica particles can induce inflammatory responses in lung tissue by activating macrophages and generating reactive oxygen species, processes that contribute to progressive fibrotic changes in the lung. Persistent inflammation and fibrotic processes associated with silica exposure may therefore result in progressive impairment of lung function among exposed workers (Leung *et al*., 2012).

In addition to the risk of lung cancer, long-term occupational exposure to crystalline silica has been associated with several other respiratory diseases, including chronic obstructive pulmonary disease and pulmonary tuberculosis in populations exposed to high concentrations of mineral dust (Leung *et al*., 2012; IARC, 2012). These findings highlight the broad range of respiratory health effects associated with prolonged silica exposure in occupational environments.

However, understanding the contribution of crystalline silica to occupational exposure in roadway environments is therefore essential for evaluating the cumulative health risks faced by street cleaners and highway maintenance workers. Silica exposure is one component of a broader mix of environmental contaminants present in transportation corridors, and its interactions with other airborne pollutants may contribute to respiratory disease risk among workers engaged in roadway maintenance and sanitation activities.

Biological Makers Effects

Occupational exposure in roadway environments involves complex mixtures of contaminants, including metal-enriched road dust, traffic-related particulate matter, diesel exhaust particles, polycyclic aromatic hydrocarbons, and mineral dust containing crystalline silica (Amato *et al*., 2014; Fussell *et al*., 2022; Thorpe & Harrison, 2008). Evidence from environmental health research indicates that these mixtures can affect biological systems through overlapping pathways, most prominently oxidative stress, inflammation, mitochondrial dysfunction, and genotoxicity (Brook *et al*., 2010; Cassee *et al*., 2013; Kelly & Fussell, 2012).

Oxidative stress represents a core mechanism linking particulate exposures and metal toxicology to downstream tissue injury. Particle-induced oxidative stress may arise from multiple processes, including reactive surfaces of particles, surface-bound organic compounds capable of redox cycling, and transition metals that catalyze the formation of reactive oxygen species (Kelly & Fussell, 2012; Karlsson *et al*., 2008). Reviews of ambient particulate toxicity indicate that particle size, chemical composition, and emission source influence oxidative potential and the magnitude of toxicological effects (Cassee *et al*., 2013; Kelly & Fussell, 2012). This framework is directly relevant to roadway occupations because road dust and traffic-related particles frequently contain transition metals and organic compounds with strong oxidative activity (Amato *et al*., 2014; Fussell *et al*., 2022).

Photo 1: The Plight of Lagos Street Sweepers and Photo 2: Civic workers clean the road near Rani Bandh in Dhanbad, India

Heavy metals commonly found in road dust, including chromium, cadmium, nickel, and lead, have been shown to induce oxidative stress. Heavy metal toxicology reviews describe reactive oxygen species generation, depletion of antioxidant defenses, lipid peroxidation, and disruption of mitochondrial function as recurrent pathways of injury across multiple metals (Jaishankar *et al.,* 2014; Jomova & Valko, 2011; Valko *et al*., 2005). Occupational exposure to chromium has been specifically linked to oxidative stress-related biomarkers and molecular damage pathways in exposed workers. A review of chromium exposure across occupational settings reported evidence consistent with reactive oxygen species generation and downstream cellular injury, including genotoxicity and chromosomal damage, particularly among workers in industrial environments with elevated chromium burdens (Junaid *et al*., 2016). This toxicological pattern is consistent with broader mechanistic evidence indicating that transition metals can promote oxidative injury via redox cycling and interference with cellular antioxidant systems (Jaishankar *et al*., 2014; Jomova & Valko, 2011).

Non-exhaust traffic particles and resuspended road dust are also relevant contributors to oxidative burden. Road traffic non-exhaust emissions are enriched in metals derived from brake wear, tire wear, and road surface abrasion, and these source profiles have been associated with high oxidative potential in toxicological frameworks evaluating particulate composition as a determinant of toxicity (Amato *et al*., 2014; Fussell *et al*., 2022; Kelly & Fussell, 2012). Street cleaners and road workers are exposed to these particles both directly near traffic and indirectly through resuspension during sweeping and maintenance activities, providing plausible occupational conditions for repeated oxidative challenge in airway tissues.

Inflammation is a primary biological response to inhaled particulate matter and is closely linked to oxidative stress pathways. Toxicological and epidemiological syntheses describe airway inflammation as a response to particle deposition in the respiratory tract, with activation of innate immune cells and release of cytokines that drive localized and potentially systemic inflammatory signaling (Brook *et al*., 2010; Kelly & Fussell, 2012). Notwithstanding, evidence from mechanistic particle studies further supports the involvement of inflammatory pathways in response to complex particle mixtures relevant to roadway environments.

Metal exposure may further contribute to genotoxic mechanisms. Reviews of heavy metal toxicity describe oxidative DNA damage, interference with DNA repair, and chromosomal aberrations as plausible downstream outcomes of sustained oxidative stress and metal-mediated cellular disruption (Jaishankar *et al*., 2014; Jomova & Valko, 2011).

It should be noted that, evidence from environmental epidemiology indicates that particulate air pollution contributes to cardiovascular morbidity and mortality, with biological mechanisms involving systemic inflammation, oxidative stress, endothelial dysfunction, and autonomic nervous system imbalance (Brook *et al*., 2010). This evidence is relevant to roadway occupations because exposure conditions may include elevated concentrations of fine and ultrafine particles from traffic and diesel exhaust, as well as metal-enriched dust that can increase oxidative potential (Amato *et al*., 2014; Pronk *et al*., 2009). The cardiovascular pathway hypothesis is supported by mechanistic models in which inhaled particles provoke pulmonary oxidative stress and inflammation, leading to the release of mediators that affect vascular function and coagulation pathways. At the same time, ultrafine particles may also contribute via translocation or interaction with neural pathways regulating cardiovascular control (Brook *et al.*, 2010).

Diesel exhaust is a particularly relevant exposure component for cardiovascular effects due to its high ultrafine particle concentrations and organic-rich particle surfaces. Occupational exposure reviews of diesel engine exhaust document exposure determinants and measurement methods across work environments, supporting the plausibility of sustained exposure among workers operating near diesel-powered equipment and traffic sources (Pronk *et al*., 2009). The classification of diesel exhaust as carcinogenic to humans reflects the strength of long-term risk evidence, while mechanistic frameworks also recognize cardiopulmonary impacts associated with diesel particulate exposure (IARC, 2012; Brook *et al*., 2010). In roadway occupational settings, diesel exhaust exposures often coincide with non-exhaust particle exposures, resulting in a mixed particulate profile that may intensify oxidative and inflammatory pathways relevant to cardiovascular outcomes (Fussell *et al*., 2022; Kelly & Fussell, 2012).

Endocrine and reproductive pathways represent an additional biological domain relevant to environmental contaminant mixtures encountered by roadway workers (Junaid *et al*., 2016; van Tongeren *et al*., 2002; Lei *et al*., 2015). Job exposure matrix research on endocrine-disrupting chemicals highlights occupational categories in which exposure may involve pesticides, industrial organics, phthalates, heavy metals, and other substances with endocrine activity, emphasizing the challenge of characterizing exposure across heterogeneous job tasks (van Tongeren *et al*., 2002). Although street cleaning and road maintenance exposures are often framed in terms of respiratory and cardiovascular outcomes, the presence of metals, combustion-derived organics, and potentially plasticizers or other urban contaminants raises plausible endocrine-relevant exposure considerations that warrant targeted investigation (Lei *et al*., 2015; van Tongeren *et al*., 2002).

Reproductive toxicity evidence for occupational mixtures is also relevant where exposures include metals or specific organic contaminants. Heavy metal toxicology reviews describe reproductive and developmental effects among the broader spectrum of systemic outcomes associated with chronic exposure, reinforcing that airway exposure pathways can result in systemic distribution and endocrine-related effects, depending on compound properties and exposure intensity (Jaishankar *et al*., 2014; Lei *et al.,* 2015). A synthesis approach that explicitly evaluates endocrine and reproductive endpoints is therefore important for a comprehensive biological effects framework, particularly in occupational contexts where exposure mixtures are complex and may not be captured by single contaminant monitoring strategies.

Biomarkers provide an important bridge between environmental exposure characterization and biological effects. Urinary 1-hydroxypyrene has been widely evaluated as a biomarker of PAH exposure in occupational and environmental contexts, reflecting internal dose of combustion-related PAHs when confounding behaviors and environmental factors are addressed (Ciarrocca *et al*., 2014; Jongeneelen, 2001). A meta-analysis of outdoor workers reported higher urinary 1-hydroxypyrene concentrations in exposed groups relative to controls, supporting its utility for evaluating PAH related exposure among workers operating in urban outdoor environments (Ciarrocca *et al*., 2014). Biomarker evidence of internal dose is especially relevant for street cleaners and road workers, who may experience both inhalation and dermal exposure to PAH-containing particulate matter and asphalt-related emissions in roadway settings (Ciarrocca *et al*., 2014; Kim *et al*., 2013).

Occupational Health Outcomes

Respiratory disorders are among the most frequently reported health outcomes among street cleaners and road maintenance workers. Several occupational health investigations have documented increased prevalence of respiratory symptoms, including chronic cough, phlegm production, wheezing, and shortness of breath among street sweepers compared with populations not occupationally exposed to road dust (Ghosh *et al*., 2014; Sabde & Zodpey, 2008).

Pulmonary function impairment has also been reported in studies examining respiratory health among street sweepers. Investigations assessing lung function have documented reductions in spirometric indicators such as forced vital capacity and forced expiratory volume, suggesting that prolonged inhalation of particulate matter may contribute to obstructive or restrictive respiratory changes (Njeru, 2024 Occupational exposure to particulate matter generated during sweeping and waste collection activities has been identified as an important determinant of respiratory risk among sanitation workers (Ghosh et al., 2014; Njeru, 2024; Sabde & Zodpey, 2008). Environmental monitoring studies have demonstrated elevated airborne particulate concentrations during manual sweeping operations, particularly under dry conditions when accumulated road dust is easily resuspended into the breathing zone of workers (Amato *et al*., 2014). Repeated exposure to these airborne particles may therefore contribute to chronic respiratory irritation and the development of respiratory disorders among street cleaners (Ghosh *et al.,* 2014; Njeru, 2024).

Cardiopulmonary health effects have also been reported in association with exposure to particulate air pollution. Epidemiological and toxicological studies have demonstrated that inhalation of fine and ultrafine particulate matter can trigger systemic inflammatory responses and oxidative stress that extend beyond the respiratory tract (Brook *et al.*, 2010).

In addition to respiratory and cardiopulmonary outcomes, musculoskeletal disorders have also been reported among street cleaners and sanitation workers. The physical demands associated with manual sweeping, lifting waste materials, and prolonged standing or walking may contribute to repetitive strain injuries affecting the lower back, shoulders, and joints (Alie *et al*., 2023). Occupational injuries have also been frequently documented in this workforce, particularly in work environments characterized by traffic exposure, manual waste handling, and physically demanding tasks (Sabde & Zodpey, 2008; Alie *et al*., 2023).

Discussions and Conclusion OR Research Gap and Conclusion

Research Gap

Despite the growing body of research examining environmental contamination in urban transportation environments, important gaps remain in understanding the health risks faced by street cleaners and road maintenance workers. Existing studies have documented the presence of multiple environmental contaminants in roadway settings, including heavy metals, polycyclic aromatic hydrocarbons, particulate matter, diesel exhaust emissions, and crystalline silica (Amato *et al*., 2014; Kelly & Fussell, 2012; Thorpe & Harrison, 2008). Research has also demonstrated that these contaminants can produce biological effects through oxidative stress, inflammatory responses, and genotoxic mechanisms, contributing to respiratory and cardiovascular disease (Brook *et al.,* 2010; Jaishankar *et al*., 2014; Kim *et al*., 2013). However, much of the current knowledge regarding the toxicological effects of these pollutants has been derived from studies of the general population or from occupational groups such as industrial workers and traffic police, rather than from street cleaners and road maintenance workers specifically.

One important limitation in the existing literature concerns the limited availability of detailed exposure assessment data for sanitation workers and street sweepers. Many studies investigating air pollution exposure rely on data obtained from ambient monitoring stations or large-scale epidemiological datasets, approaches that may not adequately capture the micro environmental conditions experienced by workers performing tasks directly within traffic corridors or roadway environments (Jerrett *et al*., 2005; Nieuwenhuijsen, 2015). Street cleaning and road maintenance activities frequently re-suspend contaminated road dust, potentially producing localized particulate concentrations that differ substantially from background urban air pollution levels (Amato *et al*., 2014). The absence of detailed personal exposure monitoring data, therefore, represents a significant gap in the literature and limits the ability to quantify cumulative pollutant exposure among these occupational groups.

A further gap in the literature concerns the limited integration of biomonitoring approaches into occupational health research involving sanitation workers. Biomarkers such as urinary metabolites of polycyclic aromatic hydrocarbons, indicators of oxidative stress, and markers of systemic inflammation provide valuable tools for linking environmental exposure with biological responses in exposed populations (Jongeneelen, 2001; Kim *et al*., 2013). Although biomonitoring methods have been widely applied in occupational studies of industrial workers exposed to combustion products and chemical contaminants, their use in research focused specifically on street cleaners and road maintenance workers remains limited (Ciarrocca *et al*., 2014; Jongeneelen, 2001). Expanding the application of biomonitoring techniques could improve understanding of internal exposure levels and provide insight into early biological effects associated with chronic pollutant exposure.

Geographic disparities in available research also represent an important limitation in the literature. Many studies examining occupational health risks among street cleaners have been conducted in developing countries where sanitation work is often performed manually, and protective equipment may be limited (Sabde & Zodpey, 2008). Although these studies provide valuable information on occupational health conditions in these contexts, fewer investigations have examined street cleaning workers in highly industrialized urban environments, where traffic density, vehicle emissions, and infrastructure characteristics may yield distinct exposure profiles. Comparative studies across different urban contexts help clarify how environmental conditions and occupational practices influence health risks among sanitation workers.

Longitudinal epidemiological research is also limited for this occupational group. Much of the available literature consists of cross-sectional studies assessing respiratory symptoms or self-reported health outcomes among street sweepers. While these studies provide important preliminary evidence of occupational health risks, longitudinal research is needed to better understand the long-term health consequences of chronic exposure to roadway contaminants. Prospective cohort studies could provide stronger evidence for a link between occupational exposure to environmental contaminants and the development of respiratory, cardiovascular, or other systemic diseases over time.

CONCLUSION

Future research should also consider the role of mechanization and workplace interventions in reducing exposure among street cleaners and road workers. Advances in mechanized street sweeping technology, improved dust suppression techniques, and increased use of personal protective equipment may help reduce worker exposure to airborne contaminants. Evaluating the effectiveness of such interventions could help improve occupational health policies and workplace safety practices for sanitation workers operating in polluted urban environments.

Overall, the existing literature demonstrates that roadway environments contain multiple environmental contaminants capable of producing adverse biological effects. However, important knowledge gaps remain regarding the magnitude of exposure among street cleaners and road maintenance workers, the biological mechanisms linking these exposures to disease outcomes, and the effectiveness of strategies to mitigate occupational health risks. Addressing these gaps through integrated environmental monitoring, biomonitoring, and longitudinal epidemiological research will be essential for advancing understanding of the biological effects of environmental contaminants in this occupational population.

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